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## Abstract

Following the German Army Training Establishment Shilo (GATES) closure at CFB Shilo (Manitoba), Director General Environment (DGE) tasked Defence Research Establishment Valcartier (DREV) to conduct an environmental assessment of past training activities to determine their impacts on soils, as well as sub-surface soils, surface waters and groundwater in the training areas. The ultimate goal of this sampling campaign is to globally assess the potential contamination related to explosives and heavy metals and evaluate the total costs of decontamination, if needed, in order to establish Germany's environmental liability resulting from their use of the CFB Shilo ranges and training areas. Such an assessment requires an appropriate definition and understanding of the hydrogeological context of the site. Soils, subsurface soils and groundwater samples were collected across all the training areas and battleruns according to the sampling procedure described in this report. Explosives, $^{232}$Th, petroleum products and heavy metals analyses revealed no major problems related to environmental contamination. However some trends were observed that could be related with the firing activities. No mitigation or site remediation action is required at this time. Thorium analyses revealed a localised impact close to the targets both in surface soils. It is recommended that MILAN missiles no longer be fired at the site. Further work and analyses will be needed to fully characterise this range.

## Résumé

Suite à la fin des manoeuvres militaires allemandes à la BFC de Shilo (Manitoba), la direction générale de l'environnement (DGE) a mandaté le CRDV pour effectuer une évaluation environnementale des activités militaires passées afin de déterminer leur impact sur les sols de surface, de la sous-surface et de l'eau souterraine dans les secteurs d'entraînement. Le but ultime de cette campagne était d'évaluer globalement la contamination potentielle reliée aux explosifs et aux métaux lourds et d'évaluer les coûts totaux d'une décontamination future si nécessaire, afin d'établir la responsabilité environnementale de l'Allemagne reliée à son usage des sites de tir et d'entraînement de la BFC Shilo. Une telle évaluation requiert une définition appropriée et une compréhension du contexte hydrogéologique du site. Des échantillons des sols de la surface et de la sous-surface et de l'eau souterraine ont été prélevés dans tous les sites d'entraînement et au travers des champs de bataille selon une procédure expliquée dans ce rapport. Les analyses pour les explosifs, les métaux lourds, les produits pétroliers et le thorium 232 n'ont révélé aucun problème majeur de contamination. Cependant, des tendances d'accumulation de certains contaminants qui sont reliées aux activités de tir ont été observées. Aucune mesure de restauration ou procédure de nettoyage n'est requise pour le moment. Les analyses pour le thorium ont révélé des impacts localisés près des cibles et un patron de contamination a été observé et ce autant pour les sols de surface que les eaux souterraines. Il est recommandé de ne plus tirer de missiles MILAN sur ce site. Des travaux et des analyses supplémentaires devront être réalisés pour effectuer la caractérisation complète de ce très grand site.

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## Executive summary

The international context of demilitarization, the closure of military and the more stringent aspects of environmental law, have led to the establishment of new areas for research and development. Many activities of the Canadian Forces such as the firing of ammunition, demolitions, and the destruction of obsolete ammunition by open burning and open detonation may lead to the dispersion of energetic compounds in the environment.

It is within this context that the Defence Research Establishment Valcartier (DREV) initiated a research program to study the environmental impact of energetic materials that are found in the Department of National Defence (DND) ammunition stockpile. The Program on soil characterization positioned DND in a state of readiness and allowed the development of a unique expertise. The present study was done at Canadian Force Base Shilo, Manitoba, where German troops have trained intensively for the past 23 years. Prior to the German Army's withdrawal from Shilo, DGE tasked DREV to conduct an environmental assessment to determine the impact of training activities on soils, as well as sub-surface soils, surface water and groundwater in the training areas. The ultimate goal of this study was to assess the potential contamination by various contaminants and evaluate the total costs of future decontamination, if needed, in order to establish Germany's environmental liability due to their use of the CFB Shilo ranges and training areas. Worldwide, the present study is one of the first extensive characterization efforts on a live firing range.

To understand the potential environmental impacts caused by the German activities at CFB Shilo, a characterization of battleruns was undertaken. Soils were sampled using a compositing technique. Biomass samples were also collected to ascertain contamination by dust or phytoremediation. Subsurface soils were collected using a split spoon sampler, and the boreholes were used as observation wells. Groundwater samples were collected using newly installed wells as well as existing wells. Samples were thoroughly analysed for explosive contamination using a gas chromatography-electron capture detector (GC-ECD) method. Heavy metals concentrations and petroleum products were also assessed. Since MILAN missiles were fired at Shilo, possibly leading to thorium contamination, efforts were made to evaluate the concentrations of radioactive thorium at targeted sites. This report explains the approach and strategy taken and presents the results obtained. The analyses for explosives, thorium 232, petroleum products and heavy metals revealed no major environmental contamination. Consequently, no major mitigation or remediation measures are required at this time.

S. Thiboutot, G. Ampleman, R. Matel, R. Lefebvre, D. Paradis2001. Environmental Characterisation of Canadian Forces Base Shilo Training Area (Battleruns) Following GATES Closure TR 2001-126 Defence Research Establishment Valcartier

## Sommaire

Le contexte global de démilitarisation, de la fermeture de bases et de la sévérité croissante des lois environnementales a conduit à l'initiation de nouveau champs de recherche et de développement. Plusieurs activités des Forces Armées Canadiennes telles que l'entraînement au tir de diverses munitions ainsi que la destruction de munitions jugées désuètes ou en surplus par brûlage ou détonation extérieure peuvent conduire à la dispersion de matériaux énergétiques et d'autres contaminants dans l'environnement. C'est dans ce contexte que le CRDV a initié un programme de recherche afin d'étudier les impacts environnementaux des composés énergétiques que l'on retrouve dans les munitions canadiennes. Le programme de caractérisation de sites placé le Ministère de la Défense Nationale dans une position où il est prêt à répondre à des problèmes futurs potentiels de contamination et a conduit à l'établissment d'une expertise interne unique.

La présente étude a été effectuée sur la base des Force Canadienne de Shilo, au Manitoba. Les Allemands ont effectué des exercices de tir sur cette base depuis les 23 dernières années. Avant le retrait définitif des troupes allemandes de la base de Shilo, le Directeur Général Environnement a mandaté le CRDV afin d'effectuer la caractérisation environnementale des sites d'entraînement de la base afin de déterminer quels ont été les impacts sur les sols, les eaux de surface et souterraine de l'entraînement allemand. Le but ultime de cette étude était ainsi d'évaluer la contamination résultante et d'évaluer les coûts de décontamination s'il y avait lieu. Cette étude représente l'une des premières étude au monde de caractérisation exhaustive d'un site d'entraînement de forces armées.

La caractérisation des parcours de combat pour véhicules blindés a été entreprise afin de comprendre les impacts environnementaux causés par les activités allemandes à la base de Shilo. Les sols ont été échantillonnés selon une approche composite. Des échantillons de biomasse ont également été prélevés afin d'évaluer leur contamination soit par déposition de poussières ou encore par bio-accumulation. Des sols de sous-surface ont été prélevés à l'aide d'un échatillonneur à cuillère fendue et des puits d'observation de l'eau souterraine ont été installés. De l'eau souterraine a été prélevée dans les nouveaux puits ainsi que dans les puits déjà existants. Tous les échantillons ont été analysés pour leur contenu en composés énergétiques à l'aide d'une méthode à la fine pointe en chromatographie gazeuse et à détecteur de capture d'électrons. Les métaux lourds ainsi que les produits pétroliers ont également été inclus comme paramètres d'analyse. Compte tenu du fait que des missiles MILAN ont été tirés par les Allemands, le potentiel de contamination par le thorium 232 a également été évalué. Ce rapport présente l'approche ainsi que la stratégie utilisées ainsi que les résultats obtenus. Les analyses pour les explosifs, les métaux lourds, le thorium 232 et les produits pétroliers ne révèlent pas de problème majeur de contamination. En conséquence, il n'y a pas lieu de mettre en place des mesures correctrices majeures pour le moment.

S. Thiboutot, G. Ampleman, R. Matel, R. Lefebvre, D. Paradis. 2001. Environmental Characterisation of Canadian Forces Base Shilo Training Area (Battleruns) Following GATES Closure. TR 2001-126 Defence Research Establishment Valcartier.

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*Chart held at DRDKIM*

*If you would like to view chart, please contact DRDKIM 2-2*

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# 1. Introduction

Energetic materials are the main components of gunpowder, explosive warheads and solid rocket propellants and therefore can be found in war zones, training ranges or on industrial production sites. During this decade, many needs have already emerged related to the identification, quantification, delimitation and elimination of energetic contaminants dispersed by munitions or, present in explosives dumps, trials or destruction fields, firing areas and production sites [1-2]. The international context of the end of the Cold War resulted in the closing of many military bases and a growing awareness of environmental issues. It is within this context that the Director Research and Development Branch, through DREV, has directed some of its resources to assess and develop expertise related to the environmental risks associated with explosive compounds.

Many Canadian Forces sites used as impact areas, training ranges, and demolition and open burning/open detonation (OB/OD) ranges which were used to destroy out-of-specification materials were highly suspected of being contaminated with energetic substances as described in the literature [1-8]. To evaluate the contamination of DND sites, sampling and characterization of various ranges was performed over the last eight years and a protocol describing the different methods of sampling and the analytical chemistry was developed [9-11]. These standard sampling, analysis and data management techniques should be applied when characterizing explosives contaminated sites [12-13].

In the 1970s Germany and Canada signed an agreement to allow German military troops to conduct training and perform manoeuvres at Canadian Force Base Shilo, located in Manitoba. This exchange program was named GATES for German Army Training Exchange Shilo. For years German and Canadian soldiers trained in these battleruns using different German and Canadian weapons, tanks, and other armoured vehicles. In December 2000, Germany decided to stop training in Canada. It was generally accepted that these activities resulted in contamination caused by unexploded ordnance and that there could be potential contamination by explosives and heavy metals. Both parties agreed to cost share UXO clean-up costs and remediation costs. Another area of concern involved the use of MILAN missile containing $^{232}Th$ leading to another potential contamination problem by radioactive compounds. Accordingly, the Director General Environment (DGE) tasked DREV in the summer of 2000 to conduct an environmental assessment in the training areas to determine the level of contamination, if any, in soils, as well as sub-surface soils and groundwater.

The ultimate goal of this sampling campaign was to assess global contamination related to explosives, heavy metals and to radioactive $^{232}Th$ contamination. This information would be used to determine Germany's share of any clean up and remediation costs, if so required. This assessment required an appropriate definition and understanding of the hydrogeological context of the site. The Shilo base is located on a major aquifer that is heavily used for crop irrigation. It is therefore critical to ensure that no contamination migrates off site.

This assessment addressed four areas of concern. The contamination patterns of surface soils around targets and in the battleruns were evaluated. The unconfined aquifer underlying the training area (hydrostratigraphy, hydraulic conductivity, groundwater flow direction, etc...) and the groundwater quality were characterized. The extent of biomass contamination in the worst-case scenario locations was assessed and finally, the surface water quality was evaluated. In previous DREV studies, it was found that soils at the surface were contaminated by both energetic materials and metals in the training ranges [1,2,14-15]. It was also critical to characterize the groundwater quality, especially on such large ranges because metals and energetic materials are both mobile in sandy environments and may therefore migrate with the groundwater, thus presenting a threat to human health and the environment. Groundwater flow had to be carefully assessed to determine its velocity, direction and the quality of the groundwater. This groundwater serves as a drinking water source for the base, is used to sustain aquatic ecosystems and also serves for irrigation. Consequently, any contamination could impact on human health, the irrigated crops and the aquatic ecosystems. In fact groundwater flowing under CFB Shilo discharges into surface water in many springs south east of the range discharging into the Assiniboine River and into the Marsh Creek to the north of the range. Both are highly sensitive areas since they are wildlife and humans receptors. Epinette Creek to the north is also used for irrigation purposes. Biomass, such as prairie grass, has proven to bio-accumulate both metals and energetic materials [15]. Therefore, it could represent a high potential intake source of these compounds for wildlife. Finally, the surface water quality had to be verified since wildlife has access to it and it can also be used for irrigation purposes.

This report describes all the work carried out between April 2000 and February 2001 at CFB Shilo and the results obtained from this sampling campaign. This study was performed under the Work breakdown element 12ng11, "Characterization of DND Sites Contaminated with Energetic Materials" and was sponsored by Germany through a task from DGE. All work was done in collaboration with the "Institut National de la recherche scientifique" (INRS). DREV and INRS have both developed expertise in the characterization and the environmental fate of energetic materials in Canadian Forces training ranges and open detonation ranges. INRS (subcontracted by DREV) completed a classification of the Shilo training area in relation with the potential environmental and human health risks associated with the presence of energetic materials [16]. This classification was a good starting point for the present investigation.

## 2. Range History/Description

CFB Shilo is located 25 km south east of Brandon, Manitoba. The Base covers an area of approximately 40 000 ha as can be seen in MAP #1. The Government of Canada owns only 15 % of that land. The Manitoba government has leased the remaining part to the Government of Canada until 2013. Topographically, the Base has a relatively flat terrain with some dunes created when Glacial Lake Agassiz covered central Manitoba (Figs 1, 2). Most of the area is treeless except for the forest in the northern parts (the Douglas Marsh and the Spruce Woods Provincial Park). There are also some tree groves scattered throughout the area.

Boundaries of CFB Shilo consist mostly of rivers and parks. The southern part of the training area runs along the Assiniboine River. The Spruce Woods Provincial Park defines the eastern limit of the training area. In addition, the Spruce Woods Provincial Park constitutes the northern border. Finally, the Cornwallis Rural Municipality serves as the western limit. Around CFB Shilo, there are a few cities and rural municipalities. Shilo and Brandon represent the most populated ones.

CFB Shilo is divided into 5 regions (A,B,C,D,E) from north to south (See map # 1). The administrative buildings are located at the North-West portion of the area. The anti-tank, grenade and rifle ranges are located in the northern part of the base. Five battleruns were used primarily by the German troops and they were named Aachen, Berlin, Cologne, Deilinghofen and Essen. These battleruns are found respectively in region B, C, D and E. Each of the battleruns has its own area for petroleum refuelling named "Parkplatz". Most of the targets found in the battleruns were pop-up targets instead of static targets, which presented different problems. Consequently, different approaches had to be taken to sample the battleruns or the other ranges. This will be explained in more detail in the next section.

CFB Shilo's climate is classified as Continental. This means that winters are cold and summers are dry. Three quarters of all precipitation occurs between April and October. The remaining 25 % represent snowfall. The main annual precipitation is around 400 mm of water (this number includes the equivalent amount of water due to the snowfalls).

The bedrock essentially consists of Cretaceous shale with some traces of siltstone and sandstone. This was not observed during drilling conducted under study. Deltaic sand deposits dating from the Quaternary period (i.e. 12 000 years ago) were found over the bedrock. These deposits originated from the meetings of the Assiniboine River and Glacial Lake Agassiz. Once the glacial lake subsided, aerial erosion shaped these deposits into a series of dunes. The thickness of this layer varies from 6 m to 20 m. There are two zones where the grain sizes are different. The Stockton sand covers almost all of the training area. It is fine sand, which originates from the lacustrine deposits. Hence, it is largely propitious to erosion. As for the Miniota sand found in the southern and western part of the training area, it is distinguished by its silty and clayey composition. This kind of sand is rarely affected by erosion. The geology of the site is illustrated in Map #2.

The drainage system includes two watersheds: the Epinette Creek and the Assiniboine River. The first one passes through the military base, while the second one is located along the southern border. Both rivers flow towards the east (Figs 3, 4, appendix 1). CFB Shilo occupies part of the Assiniboine Delta Aquifer. This unconfined aquifer covers an area of 3900 $km^2$. The sand thickness is the smallest near the Assiniboine River (approximately 6 m). Between Aachen and Essen battleruns (northern part of the training area), the thickness is the highest, approximately 30 m. The value of aquifer recharge by precipitation was first approximated by Dillon Consulting at 5% of the precipitation which is only 20 mm out of the 400 mm of precipitation but this value has to be validated. The major uses of groundwater are for domestic purposes and for irrigation of farmlands that surround the base (Figs 5, 6, appendix 1).

# 3. Experimental

## 3.1 Contractors involved

The main contractor involved in the drilling and sampling campaign was Cochrane Engineering LTD, located in Winnipeg. They were retained by DND to assist in the collection of samples and data for this environmental site assessment. The services they provided included initial project co-ordination, soil and biomass sampling under the supervision of DREV personnel, borehole drilling, groundwater monitoring, well installation and well development under INRS supervision, sample handling and all other related logistics. They also hired many sub-contractors for UXO proofing (X-Tech), borehole drilling (Paddock Drilling Inc), and GPS surveys (Wardrop Engineering). The analytical work for metals and volatile organic compounds was sub-contracted to Enviro-Test Laboratory (ETL) from Winnipeg, Manitoba. Dr Conrad Gregoire from the Geological Survey of Canada (NRCan) was sub-contracted by INRS for the thorium-232 analytical work.

## 3.2 Parameters Monitored and Analytical Methods

Soil and biomass samples were analysed for metals, energetic materials and thorium-232. Groundwater and surface water samples were analysed for metals, anions, and energetic materials. In Parkplatz, soil and groundwater samples were tested for petroleum products including Volatile Organic Compounds (VOCs) and Benzene,toluene, ethyl xylene test (BTEX), with standard Method EPA 624. Metals were analysed by Inductively Coupled Plasma Mass Spectrometry, (ICP/MS) by an external laboratory (ETL) and all the parameters available by this method were included in the study. The analytical results for individual samples as well as grain size analysis curve, hydraulic conductivity and borehole logs have not been included in the present report. However all these results are available for consultation upon request to the authors. Energetic materials for soils and groundwater were analysed at DREV by Gas Chromatography/ Electron Capture Detector, a method that leads to 1 ppb detection limit for explosives. Analyses were performed with a GC HP6890 equipped with an ECD detector, an auto-injector HP7683 at an injection temperature of 250 °C. A capillary column based on phenylmethyl siloxane HP-5 (HP19095J-121) of 10.0 m x 0.53 mm was used under helium carrier gas. The temperature run used was: 100 °C/ 2 minutes, ramp of 10°C/ minute until 200 °, ramp of 15° C/minute until 280 °C, and a pause of 4 minutes at 280 °C. This method was based on recent work published in the United States [17,18]. The quantification limits obtained for energetic materials in the present study were respectively 30 ppb for soils, 50 ppb for biomass and 5 ppb for aqueous samples. Biomass samples were lyophilised, extracted and analysed according to a procedure described in the literature [2]. These higher quantification limits were due to matrix interferences encountered in the environmental samples. INRS conducted the following on site groundwater measurements: pH, electrical conductivity, temperature, dissolved oxygen and Eh. Furthermore, water level measurements, *in situ* permeability tests and groundwater flow direction and velocity measurements were also conducted. Thorium-232 was

analysed by the Geological Survey of Canada using ICP/MS with a detection limit of 5 ppt for aqueous samples.

## 3.3 Sample Handling and Treatment

Explosives are not volatile compounds and therefore, no specific precautions such as the use of sealed containers have to be taken during sampling of media containing explosives. Soil samples were based on a minimum of 20 random sub-samples and stored in polyethylene bags. The bags were immediately stored in ice coolers in the dark to avoid the photodegradation of light-sensitive compounds. The use of polyethylene bags decreased the space needed for storing samples and reduced shipping costs. The samples were shipped frozen to ETL, who split the samples in two sub-samples after a thorough hand homogenisation. One set of frozen samples was sent to DREV for explosives analysis and the other half was extracted and analysed for metals by ETL. For petroleum analysis, Parkplatz soil samples were collected in standard VOC containers and analysed by ETL. Water samples were collected and kept cold in 1 L amber glass, stabilized with sodium bisulfite (1.5 g) and sent to DREV for explosive analysis. For metal analysis, water samples were collected in standard 500 ml polyethylene bottles and acidified to a pH of 2. Soil and water samples for thorium analysis were shipped in 500 ml polyethylene jars to the Geological Survey of Canada. Biomass samples were collected in polyethylene bags, kept frozen in the dark and sent to ETL. The samples were then cut in small pieces, homogenised, split and one half was sent to DREV for explosive analysis and the other half was analysed for metals by ETL. Digestions of the plant materials and leachate procedures were done on all biomass samples for metal analysis. For explosive analysis, the biomass samples were lyophilised and extracted, as described in Reference 2.

## 3.4 Field Investigation

The field investigation included borehole drilling, monitoring well installation and development, monitoring wells testing for *in situ* hydraulic conductivity estimation and *in situ* measurements of groundwater velocity and direction. Safety proofing of all the drilling sites was done with the help of an electromagnetic device (EM-61) and a magnetometer. All soil, biomass and water sampling locations were GPS surveyed. Site plans showing sampling and well locations are shown on maps # 3 and 4.

## 3.5 Sample Nomenclature

All the collected samples were named according to the following five parts labelling system:

First part: sample type

| | |
|---|---|
| S: | Soils |
| SW: | Surface Water |
| GW | Groundwater |

B: Biomass (Prairie Grass and other species)

SS: Subsurface Soils collected during the drillings

Second part: Location by range

A: Aachen

B: Berlin

C: Cologne

D: Deilinghofen

E: Essen

BG: Background Sample

PP: Parkplatz

Third part: Identification of the sample source

Target number (1, 2 and 3) or

Well number (1 to 41) or

Background location (ex: Southwest of Berlin) or

Background location by GPS or

LS for linear sampling at XX% of the range

Where XX%=% of the overall range length

For Parkplatz, A or B (2 samples per site)

Fourth part: Identification of the sample

A or B for the linear sample, A being the closest sample from the starting point near the road access

Systematic sampling (0-1m, 1-3 m, 3-5 m, 5-10 m, 10-20 m)

Fifth part: Date of Collection

## 3.6 QA/QC

A quality assurance and a quality control program was included in this study. Background soil and surface water samples were collected away from the ranges. Also, background wells were drilled up gradient and background groundwater samples were

collected. Background biomass samples were also collected. Usually, we perform our analyses in duplicates. Due to time and budget constraints, analyses were done only once. 10 % of field replicates were sent for analysis. The contracted laboratory presented their QA-QC including surrogates and blanks, detection limits and quantification limits. Trip blanks and field blanks were also included in the QA/QC plan.

## 3.7 Safety and Emergency Plan

The sampling of an UXO contaminated area represents an increased level of risk for personnel. A safety briefing was given by the Range Control Officers to people involved in the sampling program. This briefing explained the precautions that were to be taken to avoid contact with UXO's on the ranges and also described the various types of UXO that may be found on ranges. A safety and emergency plan was also put in place for any incident that could occur while sampling water, soils and biomass. This plan was under the responsibility of the Shilo Range Control unit. When on site for sampling, personnel always had radios to contact range control unit in case of an emergency.

## 3.8 Sampling Strategy

Soil and biomass sampling was conducted under DREV's supervision while surface water and groundwater sampling was conducted under the guidance of INRS. A total number of 83 soil (8 background), 34 biomass (4 background), 34 groundwater (3 background) and 11 surface water (2 background) samples were collected.

There are five main Battleruns in Shilo which are approximately 2 km wide. It was planned to sample all battleruns. However, due to a very limited timeframe, troop training and early snow, only three Battleruns were sampled. These included Berlin, Essen and Deilinghofen. All battleruns include Parkplatz, used for parking and re-fuelling vehicles in training and firing campaigns.

Background soils samples are critical for establishing the anthropogenic contribution versus the natural contribution for all parameters. A total of 18 background soils samples were also planned for collection. However, due to the same limiting factors mentioned earlier, only 8 background samples were collected, all in the southern part of the Shilo training area. The background samples were collected in a random manner, in a circular pattern of approximately 20 meters. A minimum of 30 sub-samples were collected to form each background sample.

The initial strategy planned for soil sampling was based on the systematic sampling of the soils around a representative number of targets in battleruns. This strategy was based on previous results obtained in antitank ranges, which showed very distinct patterns of contamination around targets [2]. However, the nature and type of firing exercises conducted in the battleruns were different compared to the one in antitank ranges. In this type of firing exercises, the ammunition makes the target flip, and it pursues its flight until it reaches the end of battleruns. It was decided to modify our sampling strategy to account for this difference. We used two sampling approaches, both based on the

collection of composite samples in order to decrease the high level of heterogeneity usually observed with explosives residues in such scenarios [2].

The first sampling approach consisted of sampling a limited number of targets by using a circular systematic approach. A minimum of 20 sub-samples were collected within a radius of 1 meter, 1 to 3, 3 to 5 and 5 to 10 meter areas immediately surrounding the target areas, as shown in figures 7 and 8, appendix 1. A rope marked at the prescribed distances was fixed to a stick as close as possible to the target. Circular samplings were conducted by turning around the stick at a defined distance. All targets were sampled in a 360 degree pattern around the targets, except for target # 2 in Berlin range, which was sampled to the front of the target at a maximum angle of 120 degree since this target was at the top of a small hill and dense vegetation covered the area behind the target. Where possible, the GPS locations of the targets were recorded. These GPS locations are presented in Table 1. The elevation is reported for target # 2 in Berlin.

The second sampling approach consisted in doing a linear sampling pattern. This approach was used to evaluate if the level of contamination by metal, thorium or energetic materials followed a pattern in the battleruns. If firing activities lead to the accumulation of contaminants in soils, higher levels would have been found at the end of battleruns since most of the ammunition fired was supposedly found there and the number of UXO's would be greater in these locations. Therefore, the sampling involved the collection of composite samples at 20, 40, 60, 100 and 120 % of the length of each range. For all battleruns, an access road was located along the range. The transepts were fixed with the help of the car odometer and also with GPS positioning. The GPS locations are reported in Table 1and the linear samples correspond to the point of the access road where the sample takers started walking perpendicularly to the range. As explained earlier, the ranges are generally 2 km wide. The sample takers walked for 1.5 km in a straight direction, and started sampling on their way back. The first 500 m sampled was identified as sample B while the other 500 m was identified as sample A, sample A being the nearest of the access road (Figs 9,10, appendix 1). A minimum of 20 sub-samples were collected for two portions of 500 m along transepts of approximately one kilometer large in the middle of battleruns at each 20 % intervals from the parkplatzs. The location of all soil samples collected can be found on map # 3.

During the drilling of the boreholes, sub-surface soil samples were collected prior to the drilling of the last 2 m with a 51 mm split spoon at the depth of the middle of the screen interval of 1.52 m. All of the soil samples were sent to INRS-Géoressources laboratory for grain size analysis and hydraulic conductivity estimation. The grain size analysis of soil was made by sieving and laser analysis. There were two types of soil analysed: the sand formation and the sandy clay formation. The sand formation

*Table 1. GPS location of soil samples*

| SAMPLE ID | GPS LOCATION |
|---|---|
| Berlin LS 20 % | NA |
| Berlin LS 40 % | 61595 E 08765 N |
| Berlin LS 60 % | 63184 E 08270 N |
| Berlin LS 80 % | 64956 E 07763 N |
| Berlin LS 100 % | 0465685 E 5506055 N |
| Berlin LS 120 % | NA |
| Berlin target 1 | 63191 e 08206 N |
| Berlin target 2 | 64842 E 08055 N, elevation 317 m |
| Berlin target 3 | 0465766 E 550696 N |
| Berlin target 4 | NA |
| Berlin target 5 | NA |
| Essen LS 20 % | 62375 E 16522 N |
| Essen LS 40 % | 62481 E 16114 N |
| Essen LS 60 % | 62635 E 15738 N |
| Essen LS 80 % | 62765 e 15492 N |
| Essen LS 100 % | 63293 E 15099 N |
| Essen LS 120 % | 63796 E 14757 n |
| Deilinghofen LS 20 % | 76127 E 97572 N |
| Deilinghofen LS 40 % | 75390 E 98317 N |
| Deilinghofen LS 60 % | 74704 E 99035 N |
| Deilinghofen LS 80 % | 74536 E 00015 N |
| Deilinghofen LS 100 % | 74086 E 00815 N |
| Deilinghofen LS 120 % | 74404 E 020621 N |
| MILAN missile site | 74002 E 01401 N |
| B-BG and S-BG | 63308 E 98231 N |
| B-BG-1 and S-BG-1 | 66653 E99858 N |
| B-BG-2 and S-BG-2 | 63682 E 91050 N |
| B-BG-3 and S-BG-3 | 61044 E 03119 N |
| Spring -1 or Devils Punch Bowl | NA |
| Spring -2 or Thornbourgh Flats | NA |
| Spring -3 or Cologne range telephone | NA |
| Lake or Zone 6 Lake | NA |

had a grain size that varied from 0.5 µm to 1 mm with a mean of 350 µm. The estimated hydraulic conductivity varied between $1.3x10^{-3}$ m/s to $4.0x10^{-6}$ m/s with an geometric mean of $1.8x10^{-4}$ m/s which was in agreement with the slug test results (see section 3.9.6) of $1x10^{-4}$ m/s. The sandy clay formation had a grain size that varied from 0.5 to 400 µm with a mean of 30 µm. The estimated hydraulic conductivity varied between $8.9x10^{-8}$ m/s to $3.2x10^{-9}$ m/s with an geometric mean of $8.7x10^{-9}$ m/s.

The sediments encountered during drilling were visually described. Among the 41 boreholes, a total of four boreholes, namely SS-A-6, SS-B-6, SS-D-1 and SS-E-5, were

sampled continuously with a 51 mm split-spoon sampler for soil classification and identification. The samples were composite samples of depth 0 to 2.5, 2.5 to 5, 1 to 2, 3 to 4, 5 to 6, 7 to 8, 9 to 10, 11 to 12, 13 to 14, 15 to 16 and 17 to 18 feet. Some duplicates were also collected. A total of 15 of these soil samples were sent to Enviro Test for metal analysis. Detailed descriptions of the soil profiles were made by Cochrane Engineering personnel and were recorded in boreholes logs. Additional soil samples were also obtained along the screen interval directly from the auger to make the calibration-curve in the laboratory for the groundwater velocity measurements in the field with the GEOFLO flowmeter (see section 3.9.9).

Parkplatz soils were sampled at each of the five battleruns for traces of volatile organic compounds (VOCs) and BTEXs. Two composite samples were randomly collected at each parkplatz and named samples A and B. The composite samples were formed of a minimum of 20 sub-samples (Fig. 11, appendix 1). For thorium-232, the target areas for the MILAN missiles were identified and the approach using the circular pattern was applied to collect soil samples. The areas were swept for radioactivity (Fig. 12, appendix 1). No radioactivity was detected which was not surprising since the half-life of $^{232}Th$ is very long and the radiation is emitted very slowly. In order to detect such low emission sources, a special detector should have been used and left in place for days [19]. Nevertheless, soil samples were collected and sent for analysis.

Biomass sampling consisted of collecting composite samples of indigenous living plants. A minimum of 20 sub-samples of mixed biomass material were collected along each soil sampling transepts of the Berlin range and on selected transepts of the Essen and Deilinghofen Ranges (Fig. 13, appendix 1). Only the plant stem, without roots, and leaves were collected. Samples were collected by cutting various types of plants in a random approach. The approach used was the same as the one used for soils. Samples A and B were collected on a 500 m distance transept lines in the middle of the battleruns. A few background samples were collected mainly south of the Shilo training area. A total of 26 biomass samples were collected in, and around the training areas. The samples, their identification and their corresponding Enviro-Test Laboratory (ETL) identification numbers are presented in table 2. The number of biomass samples was kept as low as possible since each sample was analyzed for metals both inside and on the plants. Metals that could be either inside the plants following bio-accumulation or on the plant (accumulated by deposition of dust) were evaluated by digesting the biomass samples using a standard procedure in nitric acid. A portion of the biomass samples was leached for 48 hours in distilled water and a volume (100 mL) of this aqueous solution was collected, acidified with nitric acid and then analysed. These results were named as biomass leachates in tables, and this procedure was used to discriminate the metal that was found in or on the plants. For energetic materials, lyophilisation of the entire biomass material was done so the concentrations represent the total amounts in and on the plants.

*Table 2. Biomass Extracts and Leachates Identification*

| SAMPLE ID | ETL ID NUMBER (EXTRACTS) | ETL ID NUMBER (LEACHATES) |
|---|---|---|
| B-B-LS 20 % A | A84181 | A84203 |
| B-B-LS 20 % B | A84182 | A84204 |
| B-B-LS 40 % A | A84183 | A84205 |
| B-B-LS 40 % B | A84184 | A84206 |
| B-B-LS 60 % A | A84185 | A84207 |
| B-B-LS 60 % B | A84186 | A84208 |
| B-B-LS 80 % A | A84187 | A84209 |
| B-B-LS 80 % B | A84188 | A84210 |
| B-B-LS 100% A | A84189 | A84211 |
| B-B-LS 100% B | A84190 | A84212 |
| B-B-LS 120% A | A84191 | A84213 |
| B-B-LS 120% B | A84192 | A84214 |
| B-E-LS 40 % A | A84193 | A84215 |
| B-E-LS 40 % B | A84194 | A84216 |
| B-E-LS 80 % A | A84195 | A84217 |
| B-E-LS 80 % B | A84196 | A84218 |
| B-E-LS 80 % B (dup) | A84197 | A84219 |
| B-D-LS 40 % A | A84198 | A84220 |
| B-D-LS 40 % B | A84199 | A84221 |
| B-D-LS 80 % A | A84200 | A84222 |
| B-D-LS 80 % B | A84201 | A84223 |
| B-D-LS 80 % B (dup) | A84202 | A84224 |
| B-BG-61044 E | A84355 | A89869 |
| B-BG1-63308 E | A84356 | A89870 |
| B-BG2-66653 E | A84357 | A89871 |
| B-BG3-63682 E | A84358 | A89872 |

## 3.9 Hydrogeological Survey

### 3.9.1 Safety Proofing

A level 2 clearance proofing was conducted by XTECH Explosive Decontamination Inc. prior to drilling at all well locations in order to ensure the safety of drilling and technical personnel. The XTECH personnel along with Range Control using GPS conducted an electronic ordnance avoidance search at 37 locations in preparation for the drilling. The 37 drilling sites were cleared using the following procedure. A 2 m radius was swept with an electromagnetometer Geonix EM61, then repeated using a magnetometer Forester Search Instrument. At every site a 4 feet stake with red ribbon was placed in the centre and marked as cleared with the date and the drilling site number.

### 3.9.2 Borehole Drilling

Drilling and installation of groundwater monitoring wells was conducted in October 2000. Forty-one (41) wells were drilled by Paddock Drilling Ltd (Brandon, MB) and installed by Cochrane Engineering Ltd (Winnipeg, MB) over the range under the guidance of INRS (Map # 4). Well locations were selected at the areas deemed best suited for the present investigation, in terms of their representative location, and the ease and safety of site access and well positioning. In total, 29 boreholes were drilled using a Canterra rig and 12 boreholes were drilled with a Nodwell-Brat 22, a caterpillar rig used for difficult access areas. Both of these rigs were equipped with a hollow stem auger. To determine the depth of the water table, a probe hole was first drilled with a 125 mm solid stem auger and backfilled with bentonite. Then, a 200 mm diameter borehole was drilled using the hollow stem auger for well installation and placed at least 1 m away from the probe hole. The borehole was drilled down through 2 m below the depth of the water table.

### 3.9.3 Equipment Decontamination

To avoid cross-contamination between drilling sites, the drilling bit, augers and sampling equipment were decontaminated using the following procedure.

1. Washed with high pressure water and brushed in tap water with a non-phosphated detergent.
2. Washed with a solution containing 10% hydrochloric acid.
3. Rinsed with distilled (purified) water.
4. Cleaned with acetone.
5. Final rinse with distilled water.

The Parkplatz wells namely GW-A-1, GW-B-1, GW-C-1, GW-D-1, GW-E-1 were exceptions to this procedure and instead the equipment was cleaned with hexane, rinsed with acetone (No 4) and then rinsed again with acetone and distilled water. This procedure can be seen in Figure 14, appendix 1.

### 3.9.4 Monitoring Wells Installation

Monitoring wells were installed according to ASTM-D5092-90 standard. All of the wells were made of 51 mm PVC tubing and a 1.5 m long well screen (0.010 inch slotted) with the exception of wells GW-GRE and GW-RIF where a 3.05 m well screen was placed due to the absence of threaded 1.5 m well screen. A silica sand pack was placed around the screened interval in 16 out of 41 wells. For the remaining wells the sand pack was either partially placed or not provided around the screen since the sand formation collapsed

under the water table immediately after drilling. In such cases, the *in situ* sand formation is directly in contact with the screen. The silica sand packs extend from 0.6 to 1 m above the screened interval. The annular space between the PVC tubing (51 mm) and the borehole wall (200 mm) was filled with bentonite grout up to 0.6 to 0.9 below the soil surface. A cement seal fills the rest of the annular space up to the surface as requested by CFB Range personnel. All wells were cased with a flush-mount protective casing and a locking cap (Figs 15 and 16,). The exception was well GW-A-7 where a stick-up of 1m protective casing was used as this area is prone to floods during spring-time. A 13 mm high density polyethylene (HDPE) tubing equipped with a D-32 foot valve and about 15 cm extra length was placed inside the 51 mm PVC tubing to allow the development of the well and the groundwater sampling with a Waterra pump.

### 3.9.5 Monitoring Well Development

Well development involved removing fine sediment particles in soil around the screened interval and the sand pack by pumping water from each well with a surge block. The purpose of the well development was to obtain a representative groundwater sample (i.e. one that had no sediments inside). The well development was a longer process than expected because the sand pack grain size was too large for the grain size of the sand formation and because the *in situ* sand formation was sometimes in direct contact with the screen of the well. The well development was done shortly after its installation.

Well development was made with an electric Waterra Hydrolift II pump that used an arm attached to the tubing and that extended downward toward the bottom of the well screen (Fig. 16, appendix 1). A one-way foot valve and a surge block were attached to the end of the tubing. This allowed water and sediments to flow into the tubing during the down stroke into the well, then close as the arm moved upward, lifting the water column and fine sediments 150 mm per stroke. When the water being pumped from the well became clear and free of sediment, the tubing was raised 150 mm to begin developing the next section of the screen. This process continued until the entire length of the screen had been developed below the water table. The process of well development typically took 12 to 16 hours per well with some wells taking considerably longer. Well development took place at three wells simultaneously, with each well using one of three available pumps.

Well development occurred shortly after the first wells were drilled, in mid October 2000 until early November 2000. Training exercises interrupted well development for approximately one week. However, over this time frame, 35 of 41 wells were developed in the five training ranges, the rifle, grenade and rocket ranges and the background well located off the base to the north. Seven wells remain undeveloped.

Wells GW-B-1 and GW-E-5 were partially developed, but the pumps at these wells were removed during an intense winter blizzard. After the storm, snowdrifts on the trails made these two wells and well GW-D-8 inaccessible and no further development of these wells was possible. Well development at wells GW-D-1A and GW-D-1B was initiated but did not continue on well GW-D-1A because the depth of the well was beyond the practical lifting capacity of the pump. Well GW-D-1B was not developed because the well contained no water when examined prior to development. Well GW-D-4 had also been initially developed, but was pumped dry. Well GW-B-2 was not developed because it could no longer be located. Numerous efforts were undertaken in an attempt to find this well including GPS location references and extensive site surveys, but the location of the well remained unknown. Map and Flag operations had been performed by an explosive ordnance disposal (EOD) team throughout the range prior to the development of Well GW-B-2 and the EOD team had marked UXO's with the same flags used to mark the wells which made locating well GW-B-2 very difficult.

### 3.9.6 Testing of Monitoring Wells

Slug tests were made in all developed wells for an estimation of hydraulic conductivity of the sand formation. There were two ways to perform this test at Shilo. The first one was by injecting compressed air into the well with a special device (Fig. 17, appendix 1) to drop the water table between 30 and 70 cm below its natural static level. After an instantaneous pressure release the rise in water table was recorded with a Level Logger pressure gauge (from Solinst). Data interpretation was done with the Bower Rice method [20] to evaluate the hydraulic conductivity. The second slug test method was conducted by removing water from the well with a bailer to drop the water table 60 cm below static level instead of using pressurized air. This method was used where the water table was located below the top of the screened interval. The slug tests were performed twice in each well. The hydraulic conductivity measured varied between $2.5 \times 10^{-5}$ m/s to $2.7 \times 10^{-4}$ m/s with a geometric mean of $1 \times 10^{-4}$ m/s.

### 3.9.7 Land Survey

Wardrop Engineering Inc. (Winnipeg, MB) provided GPS locations (northing and easting) of monitoring wells and elevations of the top of the PVC tubing. The error associated with GPS location is ± 2 m whereas the precision on elevation was ± 0.01 m with the technique used involved 2 GPS. (Fig. 18,).

### 3.9.8 Water Level Measurements and Water Table Map

Water level measurements were made after well development. An electronic measuring tape (RST) with a precision of ± 0.5 cm was used to record the water depth in every well in relation to the top of the PVC tubing. The water depth measurements were made during October 2000. The elevation was

calculated in relation to the survey of the well's PVC tubing. The elevation of the water table measured in wells and the elevation of surface water from the topographic map were used to make the water table elevation map (Map #5). The water table contours were calculated using linear interpolation smoothing of the fifth order in Vertical Mapper v. 2.5 software. This map shows that groundwater flows in a radial fashion in a general north to south direction. The aquifer underlying CFB Shilo is unconfined and its groundwater can be recharged directly by the infiltration of precipitation. The unconfined aquifer discharges into the Assiniboine River. The horizontal hydraulic gradient is steeper closer to the Assiniboine River than in the rest of the CFB Shilo.

### 3.9.9 Hydraulic Head Map and Groundwater Direction and Velocity

The horizontal component of groundwater velocity and direction was measured *in situ* with a flowmeter (*Geoflo 40L, Fig. 19*) within the 34 observation wells developed. The *Geoflo 40L* is a probe with eight thermistors placed around a heat source. This probe was introduced in the well and a reading was taken at two elevations within the screened interval (30 cm from the bottom of the well and 30 cm below the top of the screen) to see if groundwater velocity and direction varied with depth.

The instrument measured the propagation and the deformation of a heat pulse in groundwater. In dynamic systems like an aquifer, the heat pulse propagates with an elliptic shape and the long-axis is oriented in the groundwater flow direction. The length and the orientation of this axis can be calculated with usual trigonometric formulas. The resultant vector is fitted on a calibration curve made in laboratory using sand from the aquifer to get the groundwater velocity. As shown on Map #6, groundwater flow directions measured by the *Geoflo 40L* are consistent with the piezometric map except for four wells (GW-A-6, GW-B-6, GW-B-3, GW-GRE) where local groundwater flow was possibly affected by the water table or because of false readings of the instrument. The groundwater velocities estimated from *Geoflo 40L* (125 m/y to 508 m/y) are consistent with the velocities calculated from other field data (70 to 700 m/y with and average velocity of 350 m/y). The calculated groundwater velocity is based on the average hydraulic conductivity estimated from slug tests ($1 \times 10^{-4}$ m/s), the horizontal hydraulic gradient measured on the water table map (.002 to .02 and a mean hydraulic gradient of .01) and an estimated porosity of 0.3.

### 3.9.10 Recharge Evaluation

Groundwater recharge is the product of effective porosity and of the total of water level change observed during recharge events (snow melt). The estimation of the groundwater recharge was based on a water table hydrograph from a well located in the centre (near GW-A-2) of CFB Shilo. This well was selected because its water level was not influenced by irrigation wells. Data monitored by this well were spread between January

1983 to January 2000 and showed 19 recharge events. The recharge was evaluated to vary between 0 and 142 mm/y and the mean recharge value is 50 mm/y during the period of observation of 17 years.

### 3.9.11 Groundwater Sampling

Groundwater sampling involved the use of a Waterra Hydrolift II pump and the dedicated 31 mm HDPE tubing connected to a foot valve after the well development or well purging. The groundwater sampling protocol of the Quebec Ministry of the Environment was followed. It first includes purging of at least three pore volumes of groundwater from the filter pack, the PVC tubing and the screen prior to sampling. It also involves groundwater sample filtration in the field prior to the sample acidification of the sample for dissolved metal analysis. A special double needle device was also used for groundwater sampling for VOC to minimise volatile losses (Fig. 20, appendix 1). Physicochemical parameters were also measured in the field (T, pH, conductivity, redox potential, dissolved oxygen) with dedicated probes. A total of 34 wells out of 41 were sampled. Seven of the wells were not sampled because of the difficult access created by winter conditions (GW-B-1, GW-D-8, GW-E-5) and/or because the wells were not developed (GW-D-1A, GW-D-1B, GW-D4) or not found (GW-B-2). Four wells were sampled in duplicate for quality control (GW-A-8, GW-C-8, GW-D-7, GW-E-2). Four other wells already installed and located on the base or nearby were also sampled. These wells are OW-1, OW-2 and two wells from Manitoba Natural Resource (MW-108 and MW-112)(Fig. 21, appendix 1 ).

# 4. Results and Discussion

Soil samples results were compared to Canadian Council Ministers of Environment (CCME) soil threshold criteria and also with the mean value of background sample results for some representative metals (Table 3). None of the soil samples collected found contamination levels higher than any of the CCME threshold criteria, even for agricultural. This is a good indication that there is no major soil contamination both at surface and sub-surface levels

However, when compared to background sample results, a trend can be identified. As reported in Table 4, 24 soil samples collected in battleruns showed higher concentrations for copper, cadmium, barium, molybdenum, lead, $^{232}Th$ or zinc than the mean value for soil background samples. Twenty-two of these samples were collected around pop-up targets. This is particularly true for target # 2 at Essen Range where many parameters were higher than the corresponding background values, including radioactive thorium. This proved that even if a majority of rounds did not stop at targets, soils containing

***Table 3.*** CCME Threshold Values (TrV), *Soils Background and Mean Value for Soil Background ($BG^m$)*

| METAL | TrV* | $BG^m$ (ppm) | BG (ppm) | BG-1 (ppm) | BG-2 (ppm) | BG-3 (ppm) | Spring 1 (ppm) | Spring 2 (ppm) | Spring 3 (ppm) | Lake (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Al | na | 5000 ± 2000 | 7080 | 7620 | 7090 | 6570 | 2160 | 3160 | 4960 | 3240 |
| Ba | 750 | 180 ± 70 | 218 | 219 | 239 | 257 | 169 | 172 | 177 | 128 |
| Be | 4 | 0.5 ± 0.2 | 0.6 | 0.5 | 0.5 | 0.5 | 0.2 | 0.1 | 0.4 | 0.3 |
| Cd | 3 | 0.5 ± 0.2 | 0.6 | 0.7 | 0.7 | 0.7 | 0.2 | 0.1 | 0.6 | 0.3 |
| Cr | 250 | 9 ± 4 | 10.8 | 11.6 | 10.8 | 10.5 | 5.4 | 1.0 | 11.0 | 7.7 |
| Co | 40 | 9 ± 3 | 11.1 | 11.1 | 12.4 | 9.3 | 4.0 | 6.4 | 12.0 | 6.0 |
| Cu | 100 | 14 ± 3 | 16.5 | 15.5 | 16.4 | 14.3 | 15.2 | 17.0 | 16.0 | 10.9 |
| Fe | na | 15,000 ± 5,000 | 15600 | 15700 | 17700 | 14400 | 9390 | 25200 | 17400 | 9250 |
| Pb | 375 | 14 ± 7 | 18.6 | 21.9 | 17 | 18.4 | 4.8 | 6.0 | 16.3 | 6.84 |
| Mo | 5 | 0.7 ± 0.3 | 0.63 | 0.80 | 0.92 | 1.02 | 0.53 | 0.48 | 1.11 | 0.39 |
| Ni | 100 | 16 ± 5 | 22.7 | 21.8 | 24.2 | 18.2 | 9.9 | 6.7 | 23.2 | 15.5 |
| $^{232}Th$ | na | 3 ±2 | 2.9 | 2.3 | 3.1 | 2.2 | 1.2 | 0.11 | 3.7 | 5.2 |
| V | 200 | 16 ± 5 | 18.6 | 18.3 | 18.6 | 18.1 | 11.8 | 5.2 | 21.1 | 14.2 |
| Zn | 500 | 60 ± 40 | 93 | 87 | 81 | 121 | 24 | 4 | 67 | 39 |

metals were still found in the vicinity of the targets. However,

even if the levels found around the targets were higher than representative backgrounds, they were still lower than CCME agricultural threshold criteria. This means that the firing of rounds in battleruns did cause an accumulation of metals around pop-up targets, but not to levels of concerns. Thorium is not included as a contaminant in the CCME threshold database, and therefore there are no action levels for this element. However, results clearly show an accumulation of radioactive thorium nearby targets # 1, 2 and 3 in the Essen range. The highest concentration measured is 9.0 ppm, which is not considered as a very high hit but on the other hand represents three times the background level (tables 4 and 5). It shows the same trend that will be highlighted in the groundwater with a statistically representative concentration of thorium nearby known MILAN missiles target area.

***Table 4.*** *Soil Samples Showing Results Superior to Background Soil Samples*

| SAMPLE ID | ETL ID NUMBER | PARAMETER | CONCENTRATION (mg/kg) |
|---|---|---|---|
| S-B- LS-40%B | A84332 | Cu | 19.4 |
| S-B-LS-60%B | A84334 | Cd | 0.88 |
| S-B-1-3-5 | A84343 | Cd | 1.2 |
| S-B-1-5-10 | A84344 | Cd | 1.89 |
| S-B-1-5-10 | A84344 | Mo | 1.27 |
| S-B-2-1-3 | A84347 | Cu | 17.9 |
| S-B-3-0-1 | A84351 | Cd | 1.15 |
| S-B-5-10-20 | A84369 | Cd | 0.83 |
| S-B-5-10-20 | A84369 | Cu | 23.5 |
| S-E-2-0-1 | A84388 | Ba | 303 |
| S-E-2-0-1 | A84388 | Cd | 0.98 |
| S-E-2-0-1 | A84388 | Co | 21.5 |
| S-E-2-0-1 | A84388 | Pb | 22.4 |
| S-E-2-0-1 | A84388 | Zn | 143 |
| S-E-2-1-3 | A84389 | Ba | 262 |
| S-E-2-1-3 | A84389 | Cd | 0.99 |
| S-E-2-1-3 | A84389 | Cu | 17.6 |
| S-E-2-1-3 | A84389 | Zn | 137 |
| S-D-1-0-1 | A84410 | Cd | 0.98 |
| S-D-1-3-5 | A84412 | Cd | 0.89 |
| S-D-1-3-5 | A84412 | Zn | 126 |
| S-E-1-3-5 | A83486 | $^{232}$Th | 9.1 |
| S-E-2-3-5 | A84390 | $^{232}$Th | 6.1 |
| S-E-3-5-10 | A84395 | $^{232}$Th | 5.8 |

All the analyses for explosives revealed no soil contamination, with a quantification limit of 30 ppb.

In the Berlin battlerun, biomass samples were collected in all transepts. There are no accepted threshold criteria, neither for biomass extracts nor for leachates. Biomass extracts and leachates were thus compared to the mean values for representative metals in backgrounds samples. The mean values for background samples are presented in Tables 6 and 7. The variability in results was important for the plant extracts (Table 5)

and therefore, the standard deviations on mean values were also high. Variations for the leachates (Table 6) were smaller and a better homogeneity

***Table 5.*** Concentrations of Metals in Biomass Background Samples and their Mean Value

| SAMPLE | Al (ppm) | Cr (ppm) | Cu (ppm) | Fe (ppm) | Mn (ppm) |
|---|---|---|---|---|---|
| B-BG | 90 | 0.5 | 4.4 | 274 | 57 |
| B-BG1 | 70 | 5 | 2.9 | 144 | 46 |
| B-BG2 | 75 | 3 | 2.5 | 160 | 60 |
| B-BG3 | 96 | 4 | 3.4 | 206 | 81 |
| $BG^{Bem}$ | 83±12 | 3±2 | 3.3±0.7 | 200±50 | 61±12 |

was observed in the results. The number of background biomass samples was quite limited considering the area of the range and unfortunately only a small number of background samples were collected. The locations of the biomass background samples are presented in Map #7. Results obtained for the Berlin battlerun are presented in Tables 8 and 9 since this site was the most extensively sampled. However, the results obtained for the other battleruns for both the plants extracts and leachates were compared to the corresponding mean backgrounds and no problems were identified.

***Table 6.*** Concentrations of Metals in Biomass Background Sample Leachates and Mean Value, $BG^{BLm}$

| SAMPLE | Al (ppm) | Cr (ppm) | Cu (ppm) | Fe (ppm) | Mn (ppm) |
|---|---|---|---|---|---|
| B-BG | 0.04 | 0.002 | 0.006 | 0.24 | 0.34 |
| B-BG1 | 0.03 | 0.003 | 0.024 | 0.26 | 0.41 |
| B-BG2 | 0.04 | 0.003 | 0.031 | 0.50 | 0.52 |
| B-BG3 | 0.02 | 0.003 | 0.011 | 0.19 | 0.42 |
| $BG^{BLm}$ | 0.03±0.01 | 0.003±0.001 | 0.02±0.01 | 0.3±0.1 | 0.42±0.07 |

The concentrations of representative metals in biomass extracts of the Berlin battlerun are presented in Table 7. These results are the mean value for the A and B samples collected in linear transepts along the range. The mean background results for the same parameters were also integrated into the table for comparison. It may be noted that the results obtained from the plant extracts in the battlerun did not exceed the mean value for the corresponding backgrounds. It may also be noted that no trends were observed for the measured parameters in transepts (no rising concentration versus the distance from the beginning of the battlerun) and that there were no metals deposits on the plants along the range. Three of the results shown in the table were somehow higher than the background values. Two hits were encountered for

manganese. These were not of concern since the investigation found that manganese and iron were found in high levels naturally in the Shilo area. Also, the fact that the 20 % transept showed a high hit, indicated that this was not caused by the firing activity since

*Table 7. Concentrations of Metals in Biomass Extracts, Berlin Range at Various Range Lengths*

| METAL | 20 % (ppm) | 40 % (ppm) | 60 % (ppm) | 80 % (ppm) | 100 % (ppm) | 120 % (ppm) | $BG^{BLM}$ (ppm) |
|---|---|---|---|---|---|---|---|
| Cu | 5.2 | 4.8 | 4.1 | 5.2 | 2.3 | 4.3 | 4.3±0.7 |
| Fe | 164 | 143 | 122 | 157 | 130 | 184 | 200±50 |
| Al | 78 | 29 | 59 | 80 | 55 | 126 | 83±12 |
| Mn | 92 | 48 | 44 | 72 | 35 | 77 | 61±12 |
| Cr | 2 | 0.8 | 0.7 | 3.2 | 4.2 | 0.6 | 3±2 |

the probability of having high concentrations at the beginning of the Battlerun was very low. In fact the 20 % transept results for the battleruns may represent a background for each battlerun. The only remaining sample that showed a result higher than backgrounds was a sample collected at the 120 % transept which showed high levels for aluminium. However, this level was not critical, being only 25 % more concentrated than the corresponding background.

Table 8 presents the results obtained in the Berlin battlerun for the biomass leachates versus the percentage of the length of the battlerun. It can be observed that two results are highlighted in the 80 % transept for chromium and aluminium where significantly higher results were obtained. This could be an indication that the 80 % transept was impacted by more UXO's and led to a measurable accumulation of metals in the biomass. Levels encountered were not critical, but they may indicate a trend. This would have to be confirmed by a more extensive biomass collection and further analyses.

*Table 8. Concentrations of Metals in Biomass Leachates, Berlin Range at Various Range Lengths*

| METAL | 20 % (ppm) | 40 % (ppm) | 60 % (ppm) | 80 % (ppm) | 100 % *(ppm)* | 120 % (ppm) | $BG^{BLM}$ (ppm) |
|---|---|---|---|---|---|---|---|
| Cu | 0.03 | 0.01 | 0.02 | 0.02 | 0.008 | 0.008 | 0.02±0.01 |
| Fe | 0.13 | 0.07 | 0.2 | 0.2 | 0.13 | 0.2 | 0.3±0.1 |
| Al | 0.03 | 0.02 | 0.04 | 0.08 | 0.03 | 0.02 | 0.03±0.01 |
| Mn | 0.45 | 0.33 | 0.48 | 0.44 | 0.41 | 0.40 | 0.42±0.07 |
| Cr | 0.008 | 0.004 | 0.006 | 0.01 | 0.003 | 0.004 | 0.003± 0.001 |

Water quality was also evaluated using different probes and analyses. Groundwater was characterised mainly by a low alkalinity (170 to 240 mg/L), a low conductivity (340 to 450 mg/L for lab data and 225 to 535 mg/L for field data), a low total dissolved solids

concentration (170 to 240 mg/L), and a very low concentration in anions (below detection limits).

***Table 9. Metals Detected over CCME Threshold Limits***

| ELEMENT | LIMIT OF DETECTION (ETL LAB) ppb | CCME THRESHOLD LIMIT ppb | TYPE OF CRITERIA |
|---|---|---|---|
| Ag | 0.2 | 0.1 | Aquatic Life |
| Al | 10 | 5-100 | Aquatic Life |
| Cu | 1 | 2-4 | Aquatic Life |
| Cu | 1 | 200-1000 | Iirigation |
| Cu | 1 | 500-5000 | Livestock Watering |
| Cu | 1 | 100 | Drinking Water |
| Al | 10 | 5000 | Irrigation or Livestock Watering |
| Cr | 1 | 2-20 | Aquatic Life |
| Cr | 1 | 100 | Irrigation |
| Cr | 1 | 1000 | Livestock Watering |
| Cr | 1 | 50 | Drinking Water |
| Fe | 10 | 300 | Aquatic life or Drinking water |
| Fe | 10 | 5000 | Irrigation |
| Mn | 0.2 | 50 | Drinking water |
| Mn | 0.2 | 200 | Irrigation |
| Pb | 0.2 | 1-7 | Aquatic Life |
| Pb | 0.2 | 200 | Irrigation |
| Pb | 0.2 | 100 | Livestock Watering |
| Pb | 0.2 | 10 | Drinking Water |
| Se | 2 | 1 | Aquatic Life |
| Se | 2 | 20-50 | Irrigation |
| Se | 2 | 50 | Livestock Watering |
| Se | 2 | 10 | Drining Water |
| Zn | 6 | 30 | Aquatic Life |
| Zn | 6 | 1000-5000 | Irrigation |
| Zn | 6 | 50,000 | Livestock Watering |
| Zn | 6 | 5000 | Drinking Water |

The water quality of the Assiniboine River was characterised by a higher alkalinity (280 mg/L), higher conductivity (920 mg/L), higher total dissolved solids concentration (590 mg/L) than the ones of the groundwater of the unconfined aquifer. The presence of chloride (25 mg/L) and sulfates (205 mg/L) was also noted. The water quality of Epinette Creek showed an increase in alkalinity (180 to 335 mg/L), conductivity (340 to 610 mg/L) and total dissolved solids (180 to 340 mg/L) along its course (from SE-1 to SE-3).

Metals were analysed in the 39 groundwater samples that were collected. Table 9 presents the CCME threshold limits for aquatic life, irrigation, livestock watering and drinking water. The limit of detection of the analytical method is also shown. The metals

concentrations measured for all theses parameters were compared to these criteria. Table 10 shows metals in groundwater that were higher than CCME threshold criteria.

The background sample (GW-BGR) is located north of CFB Shilo, upstream of Epinette Creek, away from habitation and human activity. In this sample iron and manganese concentrations were high. Aluminium was also above the criteria and chromium was at the inferior limit of the aquatic life threshold criteria. These facts proved that similar results obtained for aluminium, iron, manganese and chromium in other groundwater samples may not be from anthropogenic activities. Moreover, aluminium concentrations measured in both field and trip blanks were in the order of 20 and 60 ppb and showed that this higher limit (60 ppb) should be considered as the quantification limit for aluminium and therefore results lower than these were not relevant. Moreover, aluminium concentrations of that magnitude were observed as natural background levels in the geological environment in Quebec Province [21] Three samples analysed showed high levels of silver. However, a field duplicate for one of these samples (GW-A-8) did not show concentrations above CCME criteria for silver. This implies that the silver hits for sample GW-A-5, GW-A-8 and GW-E-7 were not representative, and therefore not of concern.

Two wells installed by CFB Shilo (OW-1 and OW-2) (Table12) prior to this study and two wells from the provincial network (MW-108 and MW-112) were sampled. The CCME threshold criteria for aluminium and chromium that were exceeded were for aquatic life and did not apply to groundwater samples. Table 11 presents the results obtained for groundwater samples outside battleruns mainly in zone A of the training areas. These wells were installed to ascertain that no contamination is coming from the north part of the training area. In particular, the anti-tank, grenade and rifle ranges were suspected as possible contributors of contaminants (Figs 22-24, appendix 1). No problems were detected in any of these wells when results were compared to field, trip blanks and background samples.

Energetic materials were not detected in the 39 groundwater samples collected. However traces of TNT were seen on gas chromatograph below the quantification limit of the analytical instrument of 30 ppb. This has to be confirmed by sampling larger volumes of groundwater at each location. The samples showing traces of TNT were GW-Spring-2, GW-B-7, GW-D-6, GW-A-7, GW-A-2 and GW-MARSH 1.

VOC and BTEX were not detected in 3 groundwater samples from wells located in the parkplatz of Aachen, Cologne and Essen. Groundwater samples were not collected in the two other parkplatzs of Berlin and Deilinghofen. Thorium 232 was analysed in 14 groundwater samples (Table14). Based on the information coming from Shilo personnel, MILAN missiles were fired in the specific areas of Essen, Cologne and Deilinghofen shown on Map #3. Based on this information, groundwater samples were collected in wells located around those areas

*Table 10. Metals Found in Groundwater within Battleruns.*

| SAMPLE ID | ETL ID NUMBER | METAL (CONCENTRATION DETECTED, ppb) |
|---|---|---|
| Field blank | A79829 | Al (60) |
| Trip blank | A79830 | Al (20) |
| GW BGR | A87899 | Al(30), Cr(2), Fe(240), Mn(1570) |
| GW-A-1 | A85950 | Al (10) |
| GW-A-2 | A85948 | Al (10) |
| GW-A-3 | A85949 | Al (10) |
| GW-A-4 | A85951 | Al (20) |
| GW-A-5 | A85952 | Ag (1.6) |
| GW-A-6 | A85953 | Al (20), Ag (0.3) |
| GW-A-7 | A85954 | Al(20), Fe (330), Mn (301) |
| GW-A-8 | A87897 | Al (20), Ag (3.5), Se (2) |
| GW-A-8 dup | A87900 | Al (20), Se (2) |
| GW-B-3 | A83316 | Al (10) |
| GW-B-4 | A83317 | Al (30) |
| GW-B-5 | A83318 | Al (10) |
| GW-B-6 | A83319 | Al (70) |
| GW-B-7 | A83310 | Al (30) |
| GW-C-1 | A83315 | Al (10), Mn (52) |
| GW-C-2 | A83312 | Al (20) |
| GW-C-3 | A83313 | Al (20) |
| GW-C-4 | A83314 | Nd |
| GW-C-5 | A83311 | Al (20) |
| GW-C-6 | A80081 | Al (20) |
| GW-C-7 | A88118 | Cr (2) |
| GW-C-8 | A88119 | Al (10), Cr (2) |
| GW-D-2 | A83322 | Al (30), Mn (279) |
| GW-D-3 | A83320 | Al (30) |
| GW-D-5 | A83321 | Al (20) |
| GW-D-6 | A83323 | Al (40) |
| GW-D-7 | A88120 | Al (20), Cr (2), Se(3) |
| GW-D-7 dup | A88121 | Al (20), Cr (2), Se (3), Ag (0.7) |
| GW-E-1 | A87900 | Al (30), Mn (66.8) |
| GW-E-2 | A87901 | Al (30), Cr (2) |
| GW-E-3 | A87904 | Al(30) |
| GW-E-4 | A87903 | Al(180), Fe(320) |
| GW-E-6 | A87902 | Al(70), Fe(280), Mn(948) |
| GW-E-7 | A87906 | Al(50), Ag(1) |
| GW-Spring-1 | A79822 | Al (40), Mn (83.1), Ag (0.5) |
| GW-Spring-2 | A79823 | Al (20), Mn (193), Fe (1710) |
| GW-Spring-3 | A79824 | Al (60), Mn (146), Fe (590) |
| GW Marsh 1 | A77179 | Al (10) |

for thorium measurements. Since there is no criteria for thorium in groundwater, results were compared to the detection limit of 5 ppt. Thorium concentrations increased around targeted areas where it reached a maximum of 229 times the detection limit or 1.145 ppb in groundwater at the firing area of Deilinghofen (GW-D-3). The second highest level was detected at the Cologne battlerun where 0.907 ppb

Table 11. Metals Found in Water Samples from Wells Installed Previously on the Shilo Base

| SAMPLE ID | ETL ID NUMBER | *METAL (CONCENTRATION DETECTED, ppb)* |
|---|---|---|
| MW 108 | A88116 | Al (270), Cr (10) |
| MW 112 | A88115 | Al (20), Cr (3) |
| OW-1 | A88122 | AL (30), Cr (2) |
| OW-2 | A88117 | Al (10), Cr (3) |

of thorium in groundwater was observed in well GW-C-2. The third highest result was observed at Essen range with 0.217 ppb of thorium in well GW-E-6. The measured concentrations of $^{232}$Th- in the surrounding wells of these three sources decreased with distance and were below detection limit in groundwater collected in the 3 springs sampled away from fired areas. These results correlate very well with the results obtained for soil samples where the accumulation of radioactive thorium is observed around targets in the Essen range. More samples should be collected around other targets nearby known MILAN missiles high impact area to better assess this particular situation.

Surface samples were taken from Epinette Creek, Assiniboine River, and springs and lakes along the Assiniboine Bassin. The physicochemical parameters measured in the field (T, Eh, dissolved oxygen) were not completely determined because of a problem related to the YSI probe.

Table 12. Metals Found in Groundwater Samples Collected Outside Battleruns in Zone A, Background Sample and Field and trip Blanks

| SAMPLE ID | ETL ID NUMBER | *METAL (CONCENTRATION DETECTED, ppb)* |
|---|---|---|
| GW-SP-5: (field blank) | A79829 | Al (60) |
| GW-SP-6: (trip blank) | A79830 | Al (20) |
| GW-BGR | A87899 | Al (30), Cr (2), Fe (240), Mn (1570) |
| GW-ATR | A87898 | Al (30), Ag (0.6), Cr (2) |
| GW-RIF | A80082 | Al (10) |
| GW-GRE | A80083 | Al (20) |

Metals were analysed in 9 surface water samples collected. Table 9 presents the CCME threshold limits for aquatic life, irrigation, livestock watering and drinking water. The limit of detection of the analytical method is also shown. The metals concentrations measured for all theses parameters were compared to these criteria. Table 14 shows metals in surface water, which are higher than CCME threshold criteria.

In the upstream part of Epinette Creek (SE-1 and SE-2, Fig. 3) no concentrations of metals above CCME threshold limits were observed. In the downstream part (SE-3), a higher level of copper and manganese was measured. Iron and manganese concentrations were associated with water drained from the marsh as observed in the background

groundwater sample (GW-BGR). However the presence of copper was noted down gradient of CFB Shilo in the Epinette Creek (SE-3) and in the Assiniboine River (SA-3). This observation has to be confirmed and discussed with local authorities. Since we found no problem in soil associated with copper in battleruns and in groundwater down gradient of the range, it would not be

*Table 13. Thorium 232 Results from Groundwater Samples*

| SAMPLE | THORIUM 232 (ppb) |
|---|---|
| Blank A | < 0.005 |
| Blank B | < 0.005 |
| GW Spring 1 | < 0.005 |
| GW Spring 2 | < 0.005 |
| GW Spring 3 | < 0.005 |
| GW C2 | 0.907 |
| GW C5 | 0.062 |
| GW C6 | 0.093 |
| GW D2 | 0.010 |
| GW D3 | 1.145 |
| GW D5 | 0.041 |
| GW E2 | 0.021 |
| GW E3 | 0.033 |
| GW E4 | 0.082 |
| GW E6 | 0.217 |
| GW E2 dup | 0.054 |

related with the training activities. We learned that live firing was conducted into the marsh at Epinette Creek and this could explain the high result of copper in the creek down gradient. This would have to be re-examined to obtain a definitive conclusion.

Aluminium concentration measured in both field and trip blanks in the order of 20 and 60 ppb showed that this higher limit (60 ppb) should be considered as the quantification limit for aluminium and therefore results lower than that are not relevant. Therefore aluminium concentrations measured in the Assiniboine River above CCME aquatic life threshold were not relevant. The only concern for aluminium in surface water was related to Horseshoe Lake and Zone 6 Lake. However because Horseshoe Lake (H Lake) is intermittent the aquatic life is not of concern. Zone 6 Lake is a groundwater outcrop that was named for sampling purpose. This lake is not listed in the toponimic record of the province and therefore is not considered to be a lake. Levels of aluminium exceeded the aquatic life threshold criteria in this water body but it cannot be linked to anthropogenic contribution from the Shilo training area.

*Table 14. Metals Found over CCME Threshold Criteria in Surface Water*

| SAMPLE ID | ETL ID NUMBER | METAL (CONCENTRATION DETECTED, ppb) |
|---|---|---|
| Field blank | A79829 | Al (60) |
| Trip blank | A79830 | Al (20) |
| SE-1 | A77173 | ND |
| SE-2 | A77174 | ND |
| SE-3 | A77175 | Cu (13.6), Mn (64.8) |
| SA-1 | A77176 | Cu (2.7) |
| SA-2 | A77177 | Al (10), Cu (2.5) |
| SA-3 | A77178 | Al (10), Cu (12.0) |
| H-LAKE | A79825 | Al (290), Cu (2), Fe (690), Mn (143) |
| ZONE 6 LAKE | A79827 | Al (230), Fe (690), Mn (90.2) |
| Zone 6 lake (dup) | A79828 | Al (240), Fe (720), Mn (91.0) |

Energetic materials were not detected in the 9 surface water samples collected. However traces of TNT were seen on gas chromatograph below the quantification limit of the analytical instrument of 30 ppb. This has to be confirmed by sampling larger volumes of groundwater at HLAKE and MLAKE.Thorium 232 was analysed in 4 surface water samples (Table 15). The concentration was close to the detection limit of 5 ppt in Zone 6 Lake and three times the background

*Table 15. Thorium 232 Results from Surface Water Samples and Plant Leachate Samples*

| SAMPLE | THORIUM 232 (ppb) |
|---|---|
| Blank A | < 0.005 |
| Blank B | < 0.005 |
| B-B-LS-20% A | 0.014 |
| B-B-LS-80% A | 0.013 |
| B-B-LS-120 %B | 0.014 |
| B-B-LS-120%B dup | 0.016 |
| B-B-LS-40%B | 0.013 |
| B-E-LS-80%A | 0.018 |
| B-E-LS 80% B | 0.015 |
| B-E-LS 80 % B (dup-1) | 0.018 |
| B-E-LS 80% B (dup-2) | 0.018 |
| B-D-LS-40 % B | 0.014 |
| B-BG-61044E 031 | 0.015 |
| GW E4 | 0.082 |
| GW E6 | 0.217 |
| GW E2 dup | 0.054 |

in Hlake and Mlake samples. These thorium concentrations can be considered background values because they are the same as the ones measured in leachates recovered from plants in battleruns far from MILAN sites.

# 5. Conclusion

The analytical results obtained for the parameters tested in all types of samples showed no major environmental impacts related to the training activities. In soils, the accumulation of some heavy metals associated with ammunitions was observed around pop-up targets but not reaching levels of concern. Neither surface soil nor the sub-surface soil samples showed levels of metals higher than agricultural CCME criteria. Our study clearly demonstrated that there are no major problems associated with soil contamination. The fact that higher levels of contaminants were encountered around targets proved that the firing activity caused an accumulation of contaminants locally, but not reaching levels of concerns. However, there is one exception to this as radioactive thorium has shown to accumulate near targets in both soils and groundwater and this represents a concern. Soil samples near targets presented statistically higher results for $^{232}$Th, while results for groundwater showed ppb levels of radioactive compound, close to identified impacted area with MILAN missile. This highlights the fact that measurable impacts were found related to the use of the missile. Levels are still very low, both in soils and groundwater, but considering the very long half-life of this particular contaminant, it is still of high concern to find measurable traces of this element. $^{232}$Th has accumulated around target impact area and even if this element has a very low solubility, it is found at traces levels in the groundwater and it might migrate off range in a long-term scenario. It is therefore strongly recommended that MILAN missile firings no longer be conducted at CFB Shilo. Moreover, MILAN missile debris should be collected and disposed according to an existing procedure for radioactive materials (Fig. 25, appendix 1).

All the analyses for explosives revealed no contamination in soils, groundwater and biomass samples. Quantification limits were however higher than what is published for the method used and hopefully, these will be lowered in a future study. Energetic materials analyses showed only traces levels of energetic residues in some water samples, which were under our quantification limits. This will be confirmed in further works when a 1 ppb detection and quantification levels should be obtained, which will allow the certification that no traces level of explosives are found in the Shilo groundwater. Considering the very severe health risk threshold levels published by the EPA, it is of high importance to improve the quantification limits in the following study and to confirm the absence of energetic residues in the groundwater.

Results obtained from the biomass samples, both for metals concentrations in plants (extracts) and the metals dust on the plants (leachates) did not show levels of concerns for metals in battleruns when compared to the biomass background mean values. Only five hits were encountered in the Berlin range where some metals showed concentrations higher than for the background samples. These hits were not considered critical though. It should be noted that higher levels of chromium and aluminium were found in the 80 and 120 % transepts where the highest concentrations of UXO's are expected to be found. No hits were observed in the Essen or in the Deilinghofen battleruns.

No biomass samples were collected around targets for which systematic soil sampling was carried out. This decision was taken in order to keep the cost of the study as low as possible. This is also related to the fact that range control officers believed that the

targets should not present the highest levels of UXO's concentration since the targets are pop-up targets and that more than 90 % of the munitions fired at them do not stop but continue towards the end of the battleruns. The fact that we did not collect plants around targets is unfortunate since the trend in accumulation of metal that was observed for soils could have also been observed for the biomass. This should be examined in a future study to verify if the levels encountered around targets for plants could be of concern for a potential intake by the Shilo wildlife.

For some groundwater and surface water samples, Al, Mn, Fe, Cr, Ag and Se exceeded CCME threshold criteria. However, it was determined that iron and manganese were found in background samples at high levels and therefore, are not considered a threat to the environment. Aluminium was found in trip and field blanks at level as high as 60 ppb. Therefore, levels lower than 60 ppb should be considered not significant. Silver was detected in some samples at high levels but field replicates showed no traces of silver indicating that it was not significant at the levels measured. Chromium and selenium were detected at low levels exceeding the lower limit interval of the aquatic threshold criteria and therefore should not be considered a threat in groundwater media.

It is recommend that further work be done to fully characterize this very large site. One should keep in mind that this study was made at a regional scale and that the sampling is therefore not representative of the whole area. Point sources at the local scale could still be found in the future. The training area can be considered as a weak source with various modes of transportations for contaminants with no measurable impacts on environmental receptors outside of the range.

Worldwide, the present study is one of the first extensive characterization efforts on a live firing range. This study in itself is proof that the department of National Defence is involved and is investing time, money and effort in the topic of sustainable training. Based on the results obtained, no remedial actions have to be undertaken in the near future. On the other hand the presence of UXOs still represents a long-term threat to the environment (Figs 26-29, appendix 1). It is not known how long it will take for these UXO's to corrode, perforate, leach and behave like punctual sources of contaminants. This situation is not particular to Shilo, but still needs to be addressed.

We recommend that level I clearance be pursued on a regular basis to increased the safety of the personnel and to protect the environment by removing potential leaching sources. Another study that will involve the characterization of other Shilo training ranges such as the grenade range and antitank range and all other potential sources of contamination should be undertaken to complete this study. This effort will greatly contribute in protecting sensitive receptors down-gradient of the range and will support the sustainable training concept. (Fig. 30, appendix 1).

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# Annexes

*Figure 1. Berlin Battlerun*

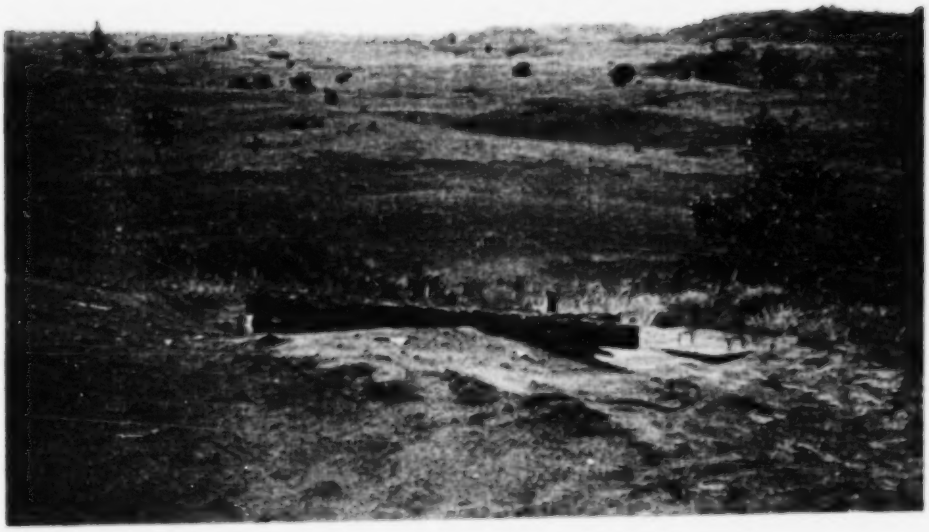

*Figure 2. A target in the Essen Battlerun*

*Figure 3. Epinette Creek*

*Figure4. Assiniboine River*

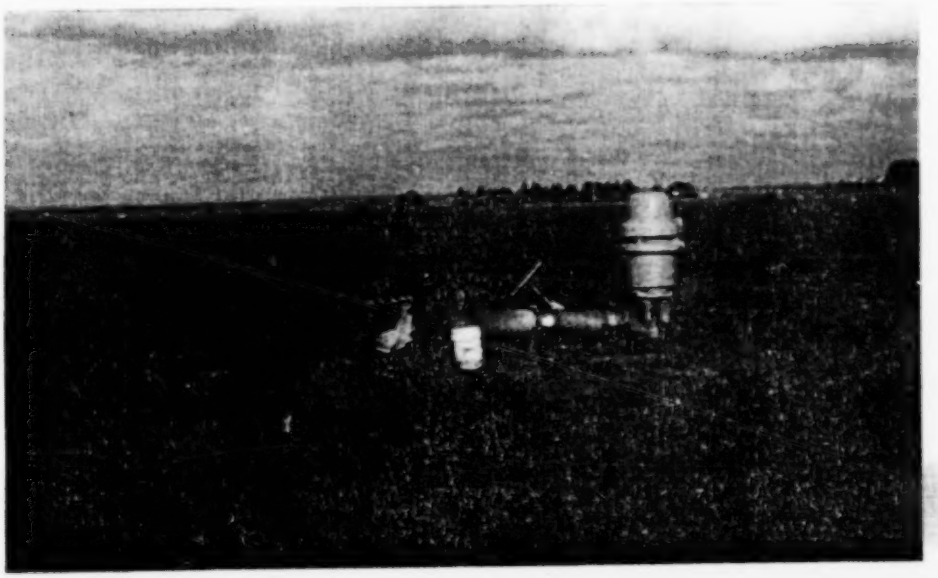

*Figure 5.Irrigation well in a farmland nearby CFB Shilo*

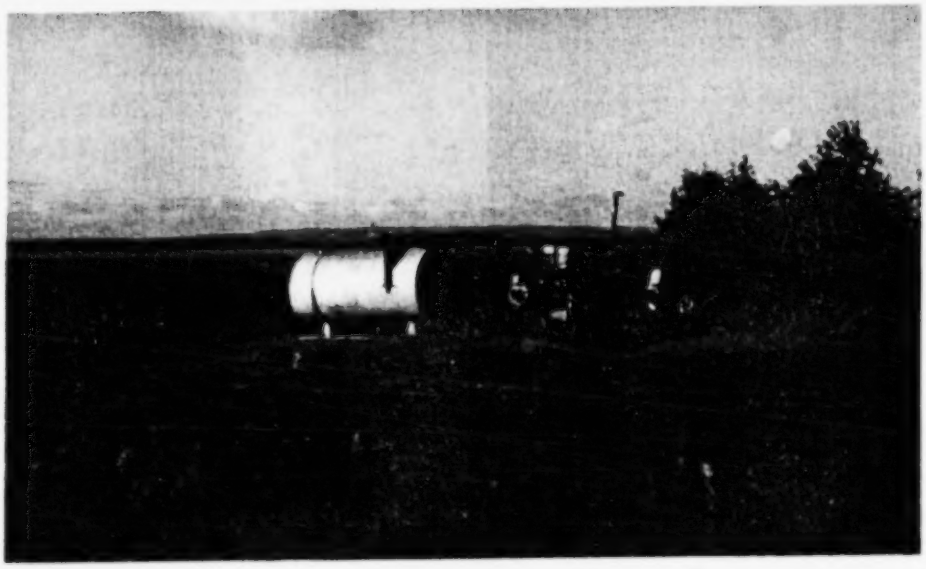

*Figure 6. Irrigation well in a farmland nearby CFB Shilo*

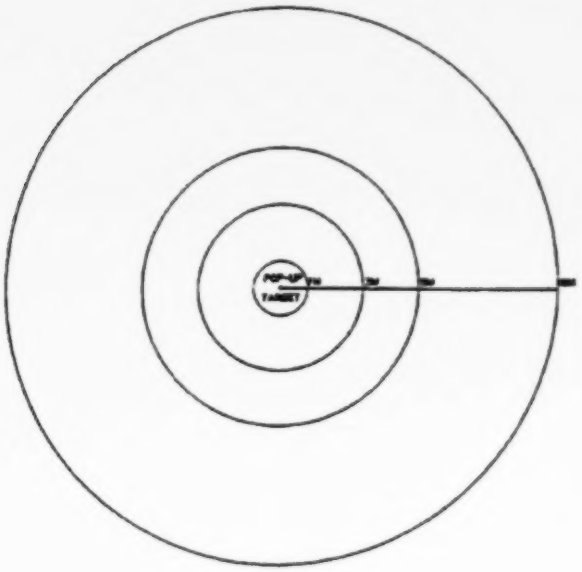

*Figure 7. Circular systemic approach to sampling*

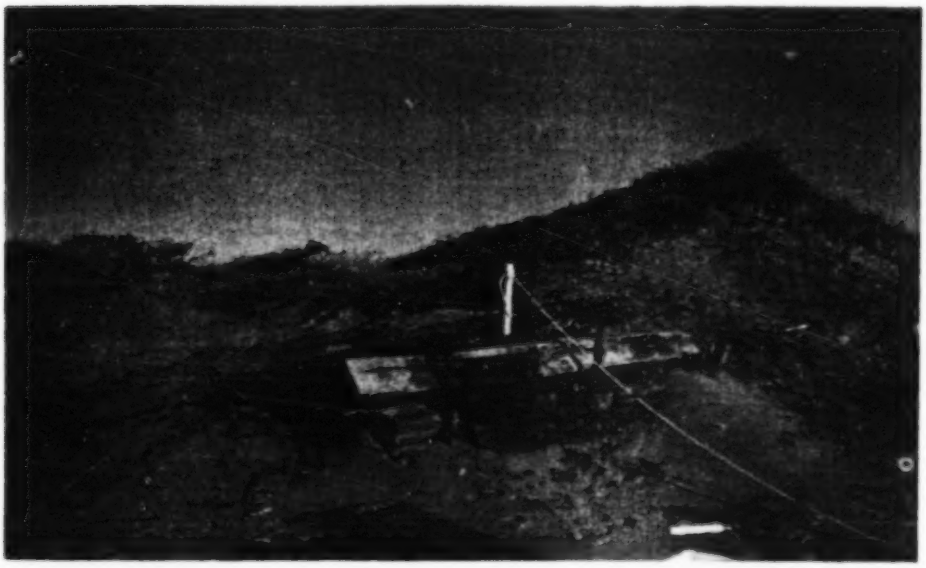

*Figure 8. C Sampling of soils in Essen target area using circular systemic approach*

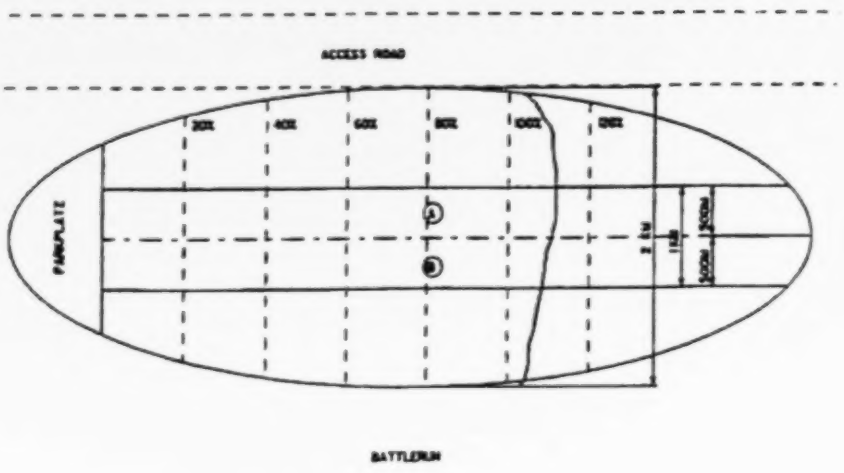


*Figure 9. Schematic view of the linear soil sampling pattern*

*Figure 10. Typical CFB Shilo topography where linear sampling was applied*

*Figure 11. Parkplatz*

*Figure 12. Sweeping for radioactivity*

*Figure 13.Biomass sampling*

*Figure 14. Equipment decontamination*

*Figure 15. Well equipped with flush mount protective casing*

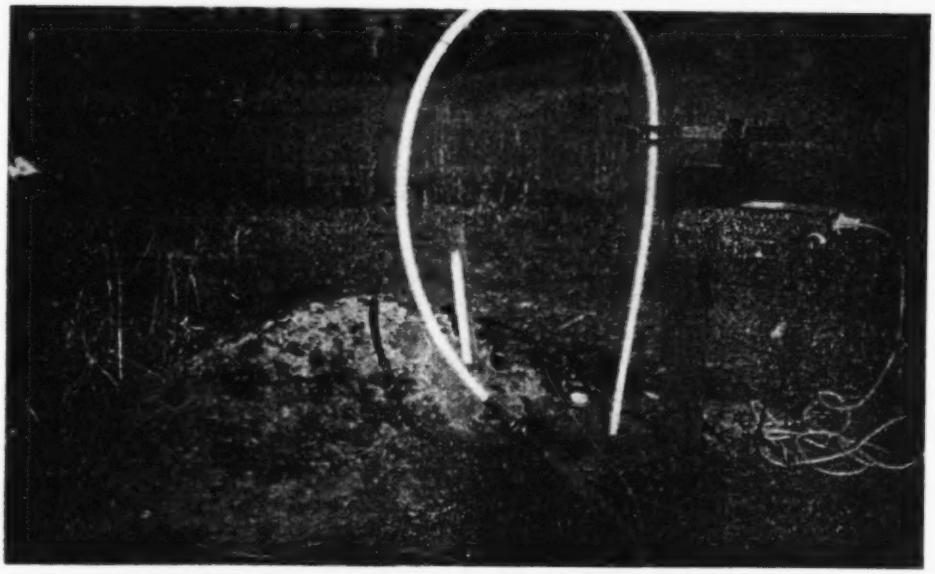

*Figure 16. Pumping of well equipped with flush mount protective casing*

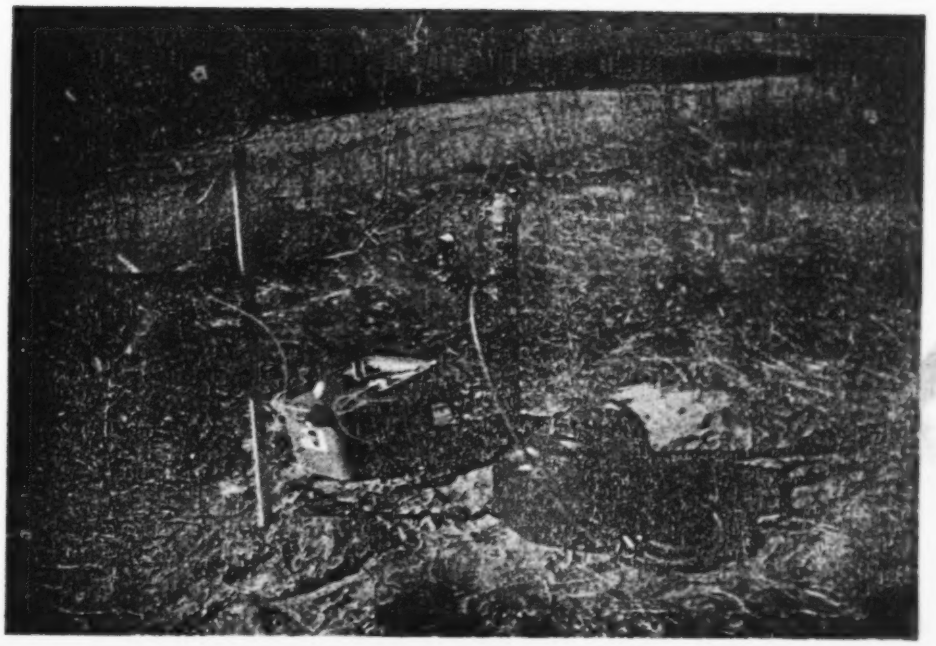

*Figure 17 Device for injecting compressed air into well*

*Figure 18. GPS location system for well land surveying*

*Figure 19. Hydraulic head measurement usig GEOFLO 40*

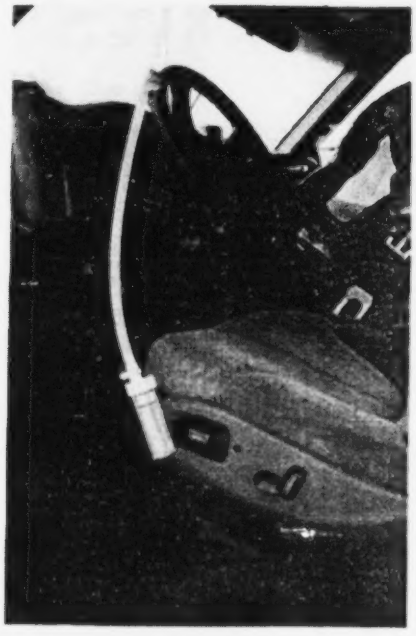

*Figure 20. Double needle device for sampling VOC's*

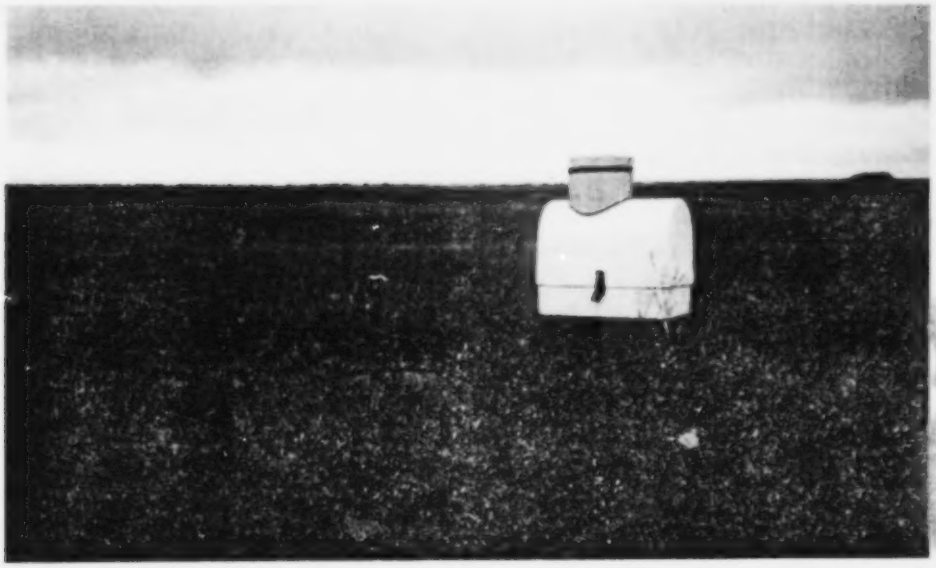

*Figure 21 Manitoba Natural Resources Well*

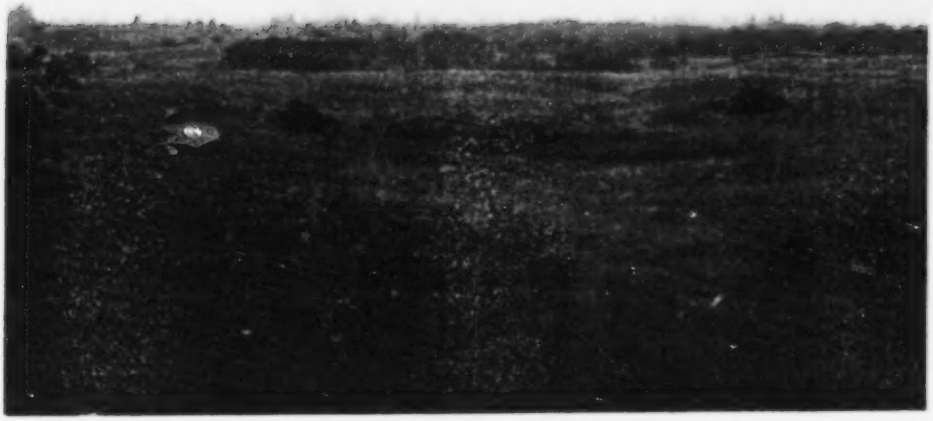

*Figure 23. Anti-tank rang, CFB Shilo*

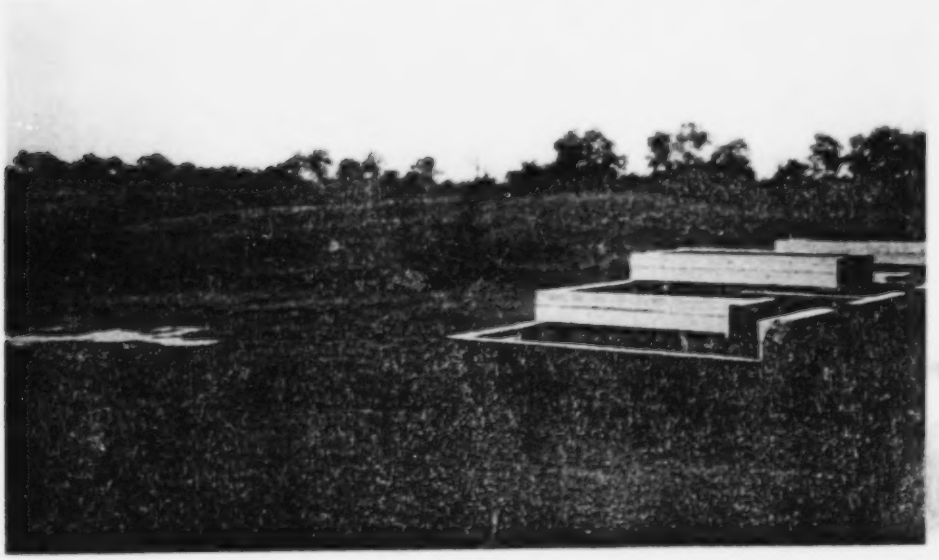

*Figure 23. Grenade range, CFB Shilo*

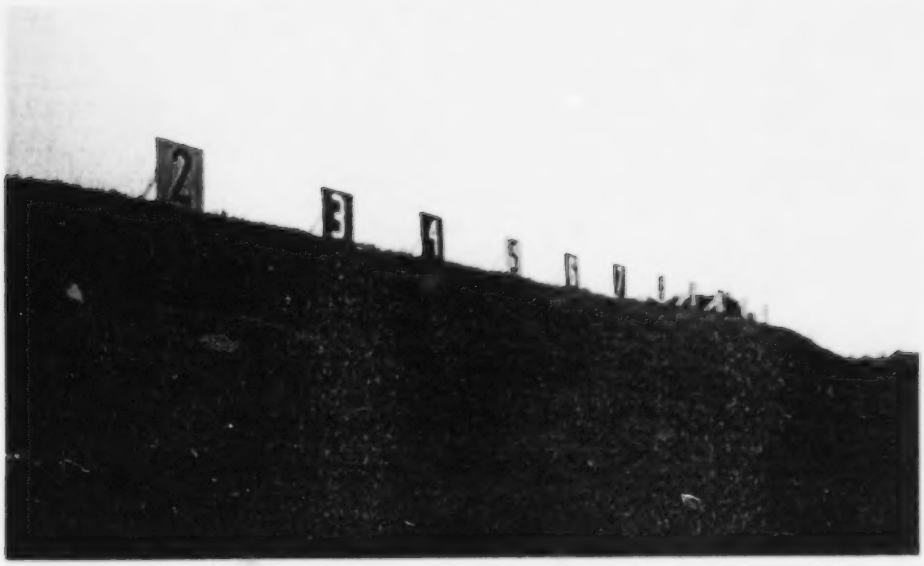


*Figure 24. Rifle range, CFB Shilo*

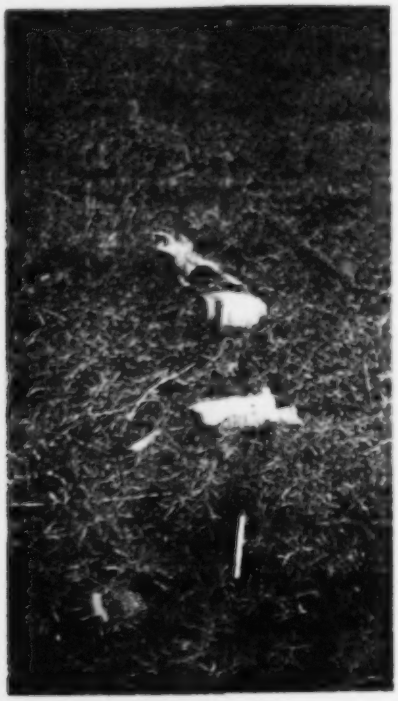

*Figure 25.MILAN missile debris*

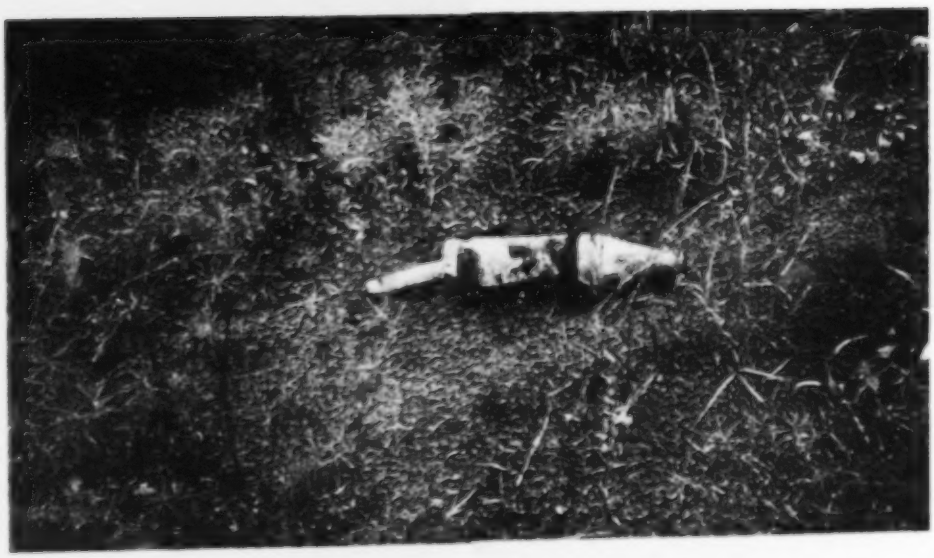

*Figure 26.Unexploded ordnance (UXO) CFB Shilo*

*Figure 27 UXO, CFB Shilo*

*Figure 28. UXO, CFB Shilo*

*Figure 29. UXO, CFB Shilo*

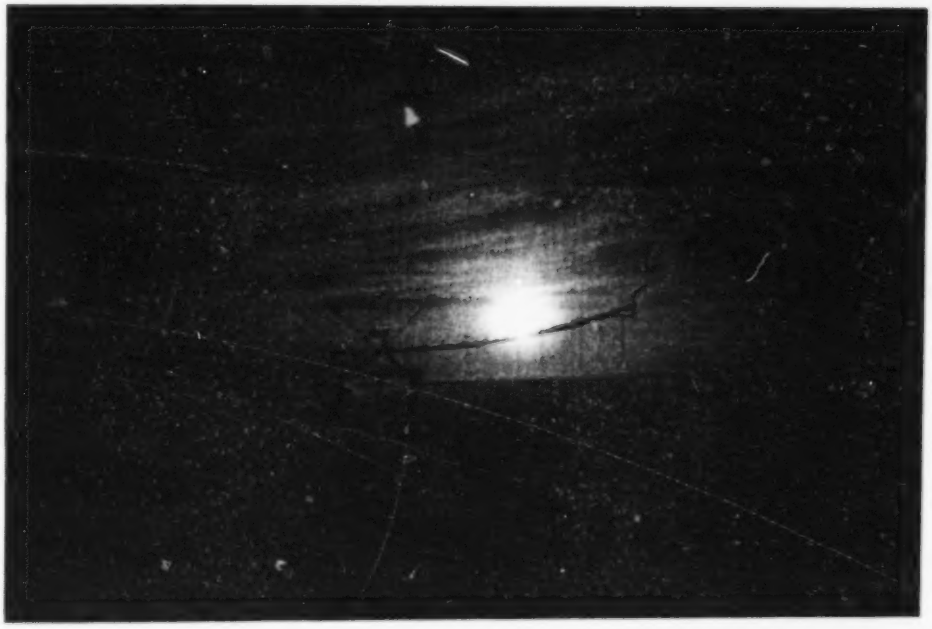

*Figure 30. Sunset, Farming area South of CFB Shilo*

# List of symbols/abbreviations/acronyms/initialisms

| | |
|---|---|
| DND | Department of National Defence |
| ASTM | American Society for Testing and Materials |
| B | Biomass sample |
| BG | Background sample |
| BETX | Benzene, Ethylbenzene, Toluene and Xylene |
| CCME | Canadian Council of Ministers of Environment |
| CFB | Canadian Force Base |
| DND | Department of National defence |
| DGE | Director General Environment |
| DNT | Dinitrotoluene |
| DREV | Defence Research Establishment Valcartier |
| EOD | Explosive Ordnance Disposal team |
| ETL | Enviro-Test Laboratory |
| GATES | German Army Training Exchange Shilo |
| GC/ECD | Gas Chromatrograph coupled with an Electron Capture detector |
| GPS | Global Positioning System |
| GW | Groundwater sample |
| HDPE | High Density Polyethylene |
| ICP/MS | Inductively Coupled Plasma /Mass spectrometer detector |
| INRS | Institut National de la Recherche Scientifique |
| LS | Linear sampling in Battleruns |

| | |
|---|---|
| mm | Millimeter |
| m/y | Meter per year |
| OB/OD | Open Burning/Open Detonation |
| PP | Parkplatz |
| ppb | Parts per Billion |
| PVC | Polyvinylchloride |
| QA/QC | Quality Assurance/ Quality Control |
| S | Soil sample |
| SS | Subsurface soil sample |
| SW | Surface Water sample |
| TNT | Trinitrotoluene |
| UXO | Unexploded Ordnances |
| VOCs | Volatile Organic Compounds |

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Following the German Army Training Establishment Shilo (GATES) closure at CFB Shilo (Manitoba), Director General Environment (DGE) tasked Defence Research Establishment Valcartier (DREV) to conduct an environmental assessment of past training activities to determine their impacts on soils, as well as sub-surface soils, surface waters and groundwater in the training areas. The ultimate goal of this sampling campaign is to globally assess the potential contamination related to explosives and heavy metals and evaluate the total costs of decontamination, if needed, in order to establish Germany's environmental liability resulting from their use of the CFB Shilo ranges and training areas. Such an assessment requires an appropriate definition and understanding of the hydrogeological context of the site. Soils, subsurface soils and groundwater samples were collected across all the training areas and battleruns according to the sampling procedure described in this report. Explosives, 232Th, petroleum products and heavy metals analyses revealed no major problems related to environmental contamination. However some trends were observed that could be related with the firing activities. No mitigation or site remediation action is required at this time. Thorium analyses revealed a localised impact close to the targets both in surface soils. It is recommended that MILAN missiles no longer be fired at the site. Further work and analyses will be needed to fully characterise this range.

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